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16. ABSTRACT The report characterizes the potential environmental effects of the multimedia waste streams from the operation of a standard-size Solvent Refined Coal (SRC-I and SRC-II) liquefaction facility utilizing 28,123 Mg of Illinois No. 6 coal per day. The report gives: (1) a more detailed evaluation of the SRC pollutants characterized in a report, Standards of Practice Manual for the SRC Liquefaction Process; (2) an estimate of the potentially adverse effects of pollutant stressors emanating from a hypothetical SRC facility on the Wabash River, White County, Illinois; and (3) substantial background information in a form usable for an Environmental Assessment Report (EAR) on SRC technology. Regulatory standards and guidelines are discussed relative to the emerging synthetic fuels technology. Research needs are identified in terms of SRC technology, monitoring, and environmental sciences. Study results indicate concern for emissions from auxiliary units (e.g., cooling towers, boilers, sulfur recovery), fugitive process discharges, solid wastes, leachate contamination of water, polycyclic aromatic hydrocarbon emissions, hazardous wastes, water treatment effectiveness, interactions within and among media, etc. Volume 2 of the report includes supporting appendices.

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Coal	Cooling Towers	Stationary Sources	21D	13A
Liquefaction	Boilers	Solvent Refined Coal	07D	
Emission	Sulfur	Synthetic Fuels		07B
Waste Disposal	Processing	Sulfur Recovery		13H
Fuels	Leakage	Fugitive Emissions		
Aromatic Polycyclic Hydrocarbons			07C	

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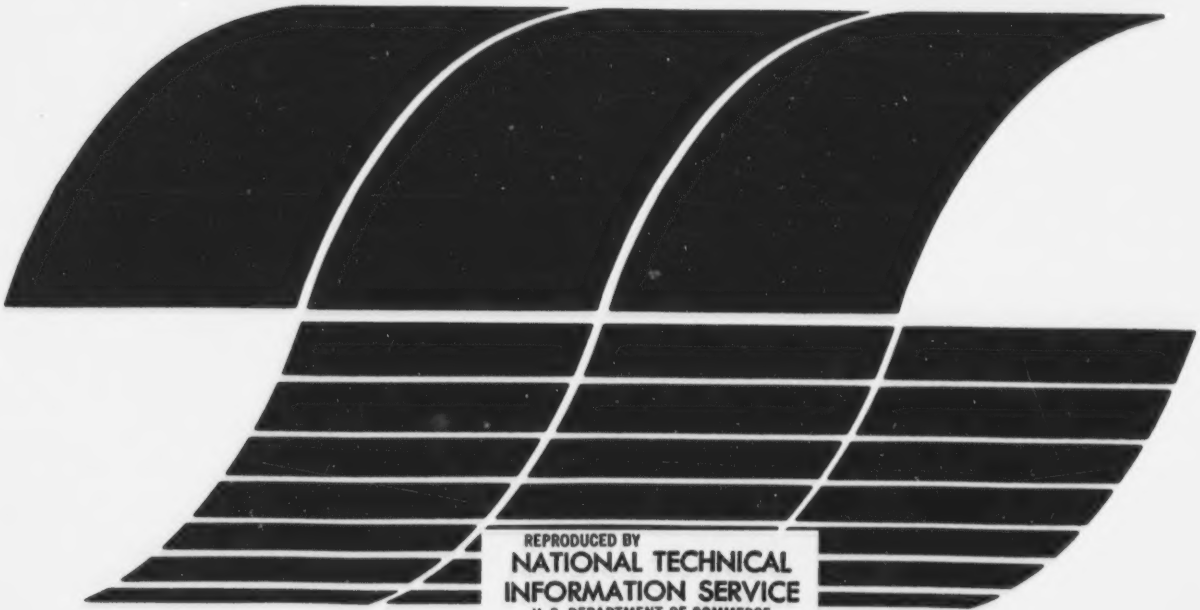

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SRC Site-Specific Pollutant Evaluation;
Volume I. Discussion

by

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ABSTRACT

This report attempts to characterize the potential environmental effects of various treated (and certain untreated) multimedia waste streams resulting from the operation of a standard-sized Solvent Refined Coal (SRC-I and SRC-II) liquefaction facility utilizing 28,123 Mg of Illinois No. 6 coal per day. The objectives of the study were to: (1) conduct a more detailed evaluation of the SRC pollutants characterized in an earlier report, referred to as the Standards of Practice Manual for the SRC liquefaction process; (2) estimate the potentially adverse effects of pollutant stressors emanating from a hypothetical SRC facility presumed to be located along the Wabash River in White County, Illinois; and (3) provide substantial background information in a form usable for the Environmental Assessment Report (EAR) on the SRC technology.

The selection of a potential site for the SRC facility is viewed as a useful construct in that this site fulfills the requirements of: (1) proximity to an abundance of water and coal, and (2) distance from public lands and sensitive terrestrial ecosystems. Extant regulatory standards and guidelines are discussed relative to the emerging synthetic fuels technology. The presently emerging Multimedia Environmental Goals (MEGs) and the Source Analysis Methodology (SAM/IA) are used to evaluate the goals and apparent safe limits for organic and inorganic pollutants resulting from operation of the SRC plant. Updated information is presented on the characteristics and quantities of effluent constituents in the multimedia context. Generic and site-specific environmental issues and constraints are discussed. Recognized abiotic and biotic interactions are discussed in relation to air and water quality, water use, land use, and threatened and endangered species of plants and animals. Pollutants of concern are discussed in terms of both site-related factors and physiochemical properties of chemical and non-chemical pollutants. Research needs are identified in terms of the SRC technology, monitoring, and the environmental sciences.

EXECUTIVE SUMMARY

INTRODUCTION

This report is one of a series in an ongoing effort to characterize the potential environmental effects of various waste streams likely associated with the operation of a standard-sized Solvent Refined Coal (SRC-I and SRC-II) facility utilizing 28,123 megagrams (Mg) of Illinois No. 6 coal per day. The objectives of this study have been to: (1) conduct a more detailed evaluation of SRC potential pollutants that were characterized earlier in the Standards of Practice Manual for the SRC liquefaction process, and (2) to estimate the potential effects of various pollutants on the environment in a multimedia context. Beyond this, an effort was made to estimate the potential environmental effects of the various pollutants associated with an SRC plant located in a known geographical area. For illustrative purposes, White County, Illinois, was selected.

This report was written in full awareness of key questions relating to the development and promulgation of regulatory standards, guidelines, and policies for an emerging synthetic fuels technology. Coupled with the already existing regulatory requirements are the presently emerging Multimedia Environmental Goals (MEGs) and the Source Analysis Methodology (SAM/IA) concepts currently being developed by the EPA/IERL-RTP. These concepts were used to evaluate the goals and apparent safe limits for major pollutants resulting from the operation of the SRC plant.

The major thrust of each of the seven sections of this report is summarized as follows:

DESCRIPTION OF THE SOLVENT REFINED COAL LIQUEFACTION PROCESS AND EXISTING ENVIRONMENTAL REQUIREMENTS

The basis for this study is a hypothetical commercial solvent refined coal (SRC) liquefaction facility which consumes 28,123 megagrams (Mg) of coal, which is equivalent to 31,000 tons (T) of Illinois No. 6 (Herrin) coal per day. The plant is presumed to be located on the Wabash River in White County, Illinois. This site was selected because of its proximity to large reserves of a process-compatible raw coal feed, the availability of an adequate water supply, and an expressed interest by the State of Illinois in coal conversion (1).

The SRC system (1) utilizes a non-catalytic direct-hydrogenation coal liquefaction process. It converts high-sulfur and -ash coal into clean-burning gaseous, liquid, or solid fuels. There are two basic system variations: (1) SRC-I, which produces a solid coal-like product of less than 1 percent sulfur and 0.2 percent ash; and (2) SRC-II, which produces low-sulfur fuel oil (0.2-0.5 percent sulfur) and naphtha product. Both system variations produce significant quantities of gaseous hydrocarbons, which are further processed in the SRC system to synthetic natural gas and liquefied petroleum gas products. Some constituents that are formed during the hydrogenation reaction are recovered as by-products. These include sulfur, ammonia, and phenol. This report is aimed primarily at the SRC-II system, which at this time seems to be the most promising alternative.

To facilitate an understanding of the basic components of the SRC system, a modular approach is taken. In the modular approach, the SRC-II system is subdivided into operations. Each operation is accomplished by carrying out a group of processes, a process being the smallest unit of the overall system. Auxiliary processes perform functions incidental to the functions of system operations. All processes may be represented visually by process modules, which display process input and output stream characteristics. Sets of process modules may be used to describe SRC system operations, the overall SRC system, or the entire coal liquefaction energy technology.

In addition to descriptions of the process modules, this chapter also includes a discussion of existing environmental requirements. No federal regulations for air, water, or solid wastes have yet been promulgated to address specifically the commercial SRC and related coal liquefaction technologies. There are, however, a number of federal regulations applicable to other industries that provide some insight into levels of control that might be required for liquefaction processes.

Environmental requirements for pollutants in states making up the major coal-bearing regions of the United States may differ significantly from federal standards. The chapter discusses state limitations on air, water, and solid wastes for the following coal regions: Northern Alaska, Four Corners (Arizona, Colorado, New Mexico, and Utah), Eastern Interior (Illinois, Indiana, and Kentucky), Fort Union-Powder River (Montana, North Dakota, and Wyoming), Texas, and Appalachian (Ohio, Pennsylvania, and West Virginia).

POLLUTANT DISCHARGE LEVELS

Emissions to the atmosphere during regular SRC plant operation are expected to arise primarily from the auxiliary unit systems. These include cooling towers, boilers, sulfur recovery, and dryers. Actual SRC process-related emissions appear to consist mostly of leaks in pump seals, joints, and flanges, and leaks from product handling and storage. These process-related emissions should be monitored as a part of the occupational health program, since they may include hydrocarbons and toxic aromatics.

Fugitive emissions (e.g., particulates) will be emitted from the following sources: coal storage piles, coal reclaiming and crushing, coal receiving, dryer stack gas, and ash from steam generation. Trace elements of fugitive emissions (i.e., dusts) from coal preparation having a potential health hazard consist predominantly of aluminum, chromium, and nickel. Present evidence suggests that trace element concentrations in particulates escaping from treated stack gas are enriched in zinc, copper, zirconium, molybdenum, and selenium.

Unquantified amounts of polynuclear aromatic hydrocarbons (PAH) are expected to be emitted with the particulates that escape air pollution control equipment. Substantial quantities of carbon dioxide (20,000 Mg per day) will emanate from several auxiliary and process units.

Insofar as the SRC process wastewaters will be treated for reuse and not for discharge, there appears to be nominal concern for cyanides, phenols, sulfides, ammonia, and dissolved solids. The concentrations of total dissolved solids from coal pile runoff may range from 247 to 44,050 mg/l; suspended solids may range from 22 to 3302 mg/l. The high alkalinity of coal from the Illinois region, however, is likely to neutralize much of the acidity in coal pile runoff, thus decreasing the solubility of the salts. Consequently, the Illinois No. 6 coal can be expected to release pollutants at the lower end of the concentration range. However, preventive measures will be required to avoid overflow from ash ponds. Placement of impervious linings on the ash pond bottoms is recommended to guard against serious groundwater pollution.

Solid wastes generated in coal preparation consist of tramp iron, slate, coal, and "bone" and amount to about 7,700 Mg per day with a moisture level of 24 percent. Leachate from solid wastes generated in the SRC process would be expected to contain appreciable levels of heavy metals, trace elements, and sulfur compounds. The expectation is that coal refuse and the SRC solid wastes such as hazardous sludges will be disposed of in strip mine areas along with slag and fly ash from the gasifier units.

The trace element concentration of coal dusts is expected to be similar to that of the parent coal, although certain trace elements have a tendency to concentrate in the smaller-sized particles. The mercury and nickel levels in the bio-unit sludge are reported to present potential health hazards. One of the largest volumes of solid wastes to be disposed of in the SRC plant is the gasifier slag and quenched fly ash, estimated at 1538 Mg per day with 40 percent water. Volatile trace elements such as mercury, selenium, and germanium are expected to be lost from the slag during disposal operations.

The 11,368 Mg per day of SRC product and by-product are considered hazardous in that they are reported to contain appreciable amounts of naphthalenes, phenanthrenes, alkyl benzenes, and other aromatics in the 343 to 511°C fraction. The several process variables that affect the distribution of these toxic substances, however, are poorly understood.

ENVIRONMENTAL DATA

Southern Illinois, southwestern Indiana, and western Kentucky have a strong orientation toward the extractive industries. This activity, coupled with extensive agricultural and industrial pursuits, has contributed materially to the stressing of the existing environment in the Wabash River Basin. For example, the Wabash and Little Wabash Rivers appear to be stressed by surface runoff of sediment and other pollutants from croplands and abandoned oil fields. Some evidence suggests that the diversity and productivity of the fishery resources of the Wabash River have already declined noticeably. Given these facts, it appears that the construction and operation of a commercial SRC facility in White County, Illinois, would not significantly change the existing air and water quality, provided that the controls described in the SRC Standards of Practice Manual (SPM) were used. Other environmental protection strategies are discussed later under the heading of ENVIRONMENTAL EFFECTS, with particular reference to environmental baseline monitoring activities.

The Wabash River is considered to have a flow volume adequate to meet the estimated 23,000 m^3/day water requirement for the SRC-II facility. This quantity of water represents 0.3 percent of the 7-day/10-year low flow volume of the Wabash River in the White County area. The stream flow volume of the Little Wabash (13,800 m^3/day) (e.g., low flows) is judged inadequate to meet the water needs of the SRC plant.

The designated site location in White County is adjacent to the Wabash Valley aquifer; this is a major aquifer capable of yielding in excess of 2,880 m^3/day. Thus, groundwater could become a major source of usable, supplemental water for the SRC facility. In general, the groundwater is more mineralized than the surface water. Some well water data reflect high chloride levels, presumably from oil well brine seepage. The deeper bedrock aquifers have very low water yields. The existing quality of surface waters appears inadequate for most SRC facility operations without prior treatment to remove nitrates and chlorides. However, no water quality standards have been established for use in the operation of SRC-II facility.

Potential constraints to the siting of the proposed SRC facility that are directly linked to the White County area include the following: prevention of significant deterioration of ambient air quality, conflicts arising between the existing agro-industrial users and future synfuels plants over consumptive in-stream water allocation, development of new underground mines, coal transportation problems linked to the mounting maintenance costs of highways and railroads, disruption of major aquifers as a result of coal extraction, regulatory constraints on developments in flood plains, increased water pumping costs, constraints to new mine development posed by existing oil well regulations, deterioration of two natural preservation areas in southeastern Illinois and approximately eight such areas in southwestern Indiana from air pollution, increased construction costs related to earthquake hazard, and accelerated loss of prime farmland to pipelines, roads, mined areas, and urbanization.

Favorable site-related factors include an abundance of Illinois No. 6 coal reserves in White County and adjacent counties to the south and west, and the relatively wide spacing intervals between the proposed facility and federal and state lands, forests, and preserves.

ENVIRONMENTAL EFFECTS

Emphasis was placed on a somewhat detailed discussion of the influence of known dissipative forces, and conversely, the known exacerbative forces operating in the environment that act to decrease, increase, or sometimes neutralize the adverse effects of many pollutants. For example, the effect of a given pollutant on organisms in a specific ecosystem (or site) is a function of the effective dose level, the chemical form and time of exposure to the pollutant, and the interplay of specific site factors that include temperature, atmospheric turbulence, stream flow volumes and rates (e.g., dilution effects), light intensity, and a host of other abiotic and biotic combinations and permutations. For example, the chemical form of a pollutant in combination with other pollutants is determinate to pollutant action via absorption, metabolism, bioaccumulation, and excretion.

This approach appears justified because of its close relation to the development of a comprehensive monitoring and information gathering program for the synthetic fuels technology envisaged by the U.S. Department of Energy.

Specific environmental effects of most pollutants are difficult to predict. The abiotic site-specific factors which determine the level of the pollutant and its actions on various receptors include the weather and, hence, are as variable as the weather. Environmental interactions with the pollutant include photoreactions to change a pollutant to a more (or less) toxic form; these also depend on the weather. The amount of pollutant to which an aquatic organism will be exposed will depend on the sediment-water interaction which, in turn, depends on the characteristics of the sediment and other materials in the water. Other environmental interactions include changing the form of a pollutant to a more or less toxic form through metabolic degradation, or by physical alteration through combustion, photochemical action, and evaporation.

This segment of the report contains a SAM/IA analysis of the hypothetical SRC facility. Results suggest that: (1) the most important gaseous emissions appear to be carbon dioxide and carbon monoxide; (2) the most important effluents appear to contain aluminum, copper, zinc, nickel, and several organic compounds; and (3) the most toxic general category of waste streams will be the solid wastes. However, these findings should be used with caution until more definitive data are obtained from a comprehensive pilot plant program and an operational demonstration plant. For example, these results may be fortuitous, either because the quantities of these substances in the waste streams are so large that they will, as predicted by the SAM, be the most important in assessing the environmental impact of the SRC facility, or because certain substances which could exert significant impacts were not included in the SAM analysis, since no information was available as to their levels in the waste streams.

The potential for the contamination of the Wabash Valley aquifer as a result of underground movement of leachate from hazardous waste disposal sites must be viewed as serious. This stems from the very long residence times once contaminants gain entry into groundwater. In order to make a valid assessment of the groundwater contamination potential, more information is needed on the site-specific soil and geologic conditions as well as the leachability characteristics of the land-disposed wastes. Disposal areas should be properly sited in areas of least potential impact. Such areas must be as far away from the path of an aquifer as possible and located on geological material that will reduce potential seepage into the groundwater.

In spite of the fact that phenols apparently are removed from wastewater at a high efficiency, there is need for caution with respect to the recalcitrance of certain higher molecular weight phenolic substances. More work is needed to establish the efficiency of the biooxidation treatment in reducing these phenolic compounds.

The PAHs are produced during the coal liquefaction process and in the coal combustion auxiliary processes. In the air and water media they are generally associated with particulate matter. The carcinogenicity of these compounds ranges from inactive, to suspect, to highly carcinogenic. The potential emission level of such carcinogenic compounds needs further study.

POLLUTANTS OF CONCERN

The MEG methodology was heavily relied upon in assessing and suggesting safe goals for the various inorganic pollutants reported to be of concern with reference to the proposed SRC facility. Because the MEGs have not addressed synergistic and antagonistic interactions, the suggestion is made that this problem might be circumvented by MEGs which deal with the "concentration of carcinogens and cocarcinogens." However, much more research will be necessary before meaningful goals can be defined in this context.

Suggesting goals for pollutant discharge levels is complicated by the complexity of the system and imprecise or incomplete scientific knowledge. Four major sources of difficulty in the setting of meaningful environmental goals include: the transport of pollutants through the media of air, water, and land; the transformation of compounds from harmless chemicals to damaging pollutants in the environment by physical, chemical, or biological means; the synergies through which two or more substances or agents interact to create a significantly more damaging effect; and the difficulty of establishing a threshold for effects when even low-level doses are suspect. The production of photochemical oxidants and the transport of air pollutants from region to region are examples of phenomena that must be better understood.

With reference to the importance of developing meaningful and comprehensive environmental monitoring and information gathering programs for the synfuels technology, it is apparent that in an overall perspective, monitoring comprises the following functional sequence: problem recognition, monitoring, evaluation of data, and formulation of policy options; within this sequence there are many feedbacks between phases. For example, a monitoring system may generate data leading to the establishment of legal emission standards. In due course, the monitoring system may be modified to insure that the standards are having the desired effect and that compliance is being achieved.

With reference to the proposed White County site, and other sites as well, it is apparent that the following site-related baseline information will be needed in order to develop the best environmental protection strategies for the following substances in the multimedia context:

- Concentrations of all regulated substances, such as those under NAAQS (see Section II of this report), Public Health Service Drinking Water, and all other environmental and occupational (OSHA) standards promulgated by Federal and state authorities
- Concentrations of all unregulated and suspected carcinogens, mutagens, and teratogens
- Concentrations of all other substances of concern.

With reference to those environmental attributes peculiar to the White County site, and for which detailed baseline, site-specific information will be required, the following actions are considered to be of major importance:

- Stream low-flow and peak-flow rates and patterns
- Assessment of groundwater contamination resulting from overland flows and seepage from the plant area, and from waste disposal areas
- Assessment of downwind effects of the cooling tower plume and of stack emissions on high dollar-value field crops and natural preservation areas
- Detailed evaluation of the subsurface soil permeabilities to liquids and gases
- Assessment of the effect of CO_2 and CO emissions on the inadvertent modification of local precipitation patterns

- Assessment of rates of dispersion and dilution of key SRC effluent pollutants in surface waters of White County, Illinois

- Assessment of rates of dispersion and dilution of heat emissions to the local atmosphere of White County, Illinois.

RESEARCH NEEDS

In the discussion of pollutant discharge levels from the hypothetical SRC facility, a number of SRC technology-related research needs were reported; these include the following:

- Leachability of all slags from gasifier and other modules

- The chemical composition of solid and hazardous wastes generated by the SRC-II technology

- The concentrations of trace elements and acidity emanating from nonvegetated refuse piles compared to vegetated refuse piles

- The amount of sediment, chemical wastes, and non-chemical wastes generated during the construction of the SRC plant

- The concentration and distribution in particulates of natural radionuclides, trace elements, and organics in or sorbed by particulate-size classes

- Comparison of the effectiveness of standard versus improved dust control measures in coal preparation, storage, and receiving areas

- Localized (downwind) environmental and vegetational effects of cooling tower plume drift in different regions

- The amount and chemical composition of catalyst dust and carbon monoxide emissions

- The cost effectiveness and feasibility of using ion exchange, reverse osmosis, and other techniques to treat cooling tower blowdown water

- The requirements for chemical stabilization of dewatered sludges

- The increased building construction costs and plant equipment costs attributable to meeting earthquake hazards

- Chemical interactions occurring among components of raw water treatment sludge

- The effect of process operating variables on the composition and volume of SRC-I and SRC-II products and by-products

- The effectiveness of various wastewater treatment methods in the removal of polynuclear aromatic hydrocarbons, higher molecular weight phenols, polycyclic N-aromatics and polycyclic hydroxy compounds.

Research needs in the areas of environmental monitoring and environmental sciences are also discussed at length.

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ABBREVIATIONS

ACGIH:	American Conference of Governmental Industrial Hygienists
AQCR:	Air quality control region
BACT/BAT:	Best available control technology/best available technology (equivalent terms)
BAPT/BPT:	Best available practical technology/best practical technology (equivalent terms)
BOD:	Biological oxygen demand (period of time unspecified)
BOD_5:	Biological oxygen demand over a 5-day period
COD:	Chemical oxygen demand
DO:	Dissolved oxygen
EOD:	Elimination of discharge
EPC:	Estimated permissible concentration
ETTA:	Effluent transport and transformation analysis
IEPA:	Illinois Environmental Protection Agency
LC_{50}:	The concentration of a substance which will cause the death of 50 percent of an experimental animal population under controlled conditions and time exposure
LD_{50}:	The lethal dose to 50 percent of a population
MATE:	Minimum acute toxicity effluent
MEG:	Multimedia environmental goals
MLVSS:	Mixed liquor volatile suspended solids
NA:	Nonattainment area

NAAQS:	National Ambient Air Quality Standards
NIOSH:	National Institute for Occupational Safety and Health
NPDES:	National Pollutant Discharge Elimination System
NSPS:	New source performance standards
PAH:	Polycyclic aromatic hydrocarbons (equivalent to polynuclear aromatic hydrocarbons)
PSD:	Prevention of significant deterioration
RCRA:	Resource Conservation and Recovery Act of 1976
SAM:	Source analysis models
SAM/IA:	A particular source analysis model
SIP:	State implementation plans
SPM:	Standards of Practice Manual
SRC:	Solvent refined coal, a method of producing an environmentally cleaner fuel from coal
SRC-I:	A solvent refined coal process which produces a solid product
SRC-II:	A solvent refined coal process which produces a liquid product
TC_{Lo}:	The lowest reported toxic concentration
TDS:	Total dissolved solids
TLV:	Threshold limit value
TSP:	Total suspended particulates
TSS:	Total suspended solids
TUDR:	Total unit discharge rate
TUDS:	Toxic unit discharge sum
VSS:	Volatile suspended solids

CONVERSION FACTORS

To convert from	To	Multiply by
	AREA	
hectare (ha)	acre (a)	2.471 044 E+00
square meter (m^2)	hectare (ha)	1.000 000 E-04
square meter (m^2)	square mile (U.S. Survey) (mi^2)	3.861 007 E-07
square kilometer (km^2)	square mile (U.S. Survey) (mi^2)	3.861 007 E-01
square meter (m^2)	acres (a)	2.471 044 E-04
square meter (m^2)	square foot (ft^2)	1.076 391 E+01
square centimeter (cm^2)	square inch (in^2)	1,550 003 E-01
	ENERGY (INCLUDES WORK)	
joule (J)	British thermal unit (International Table) (Btu)	9.478 170 E-04
joule (J)	calorie (International Table) (cal)	2.388 459 E-01
joule (J)	electron volt (eV)	6.241 46 E+18
electron volt (eV)	joule (J)	1.602 19 E-19
joule (J)	erg (erg)	1.000 000 E+07
joule (J)	kilocalorie (International Table) (Kcal)	2.388 459 E-04
joule (J)	kilowatt · hour (kW·h)	2.777 778 E-07

To convert from	To	Multiply by
joule (J)	watt · hour (W·h)	2.777 778 E-04
joule (J)	watt · sec (W·s)	1.000 000 E+00
	LENGTH	
meter (m)	inch (in)	3.937 008 E+01
meter (m)	foot (ft)	3.280 840 E+00
meter (m)	mile (International) (m)	6.213 712 E-04
meter (m)	mile (statute) (mi)	6.213 9 E-04
meter (m)	mile (U.S. Survey) (mi)	6.213 700 E-04
meter (m)	yard (yd)	1.093 613 E+00
kilometer (km)	mile (mi)	6.213 712 E-01
	MASS	
gram (g)	grain (gr)	1.543 236 E+01
kilogram (kg)	grain (gr)	1.543 236 E+04
gram (g)	ounce (avoirdupois) (oz)	3.527 397 E-02
kilogram (kg)	ounce (avoirdupois) (oz)	3.527 397 E+01
kilogram (kg)	pounds (avoirdupois) (lb)	2.204 622 E+00
kilogram (kg)	ton (short, 2000 lb) (T)	1.102 311 E-03
megagram (Mg)	ton (short, 2000 lb) (T)	1.102 311 E+00
megagram (Mg)	gram (g)	1.000 000 E+06
kilogram (kg)	gram (g)	1.000 000 E+03
milligram (mg)	gram (g)	1.000 000 E-03
microgram (μg)	gram (g)	1.000 000 E-06

To convert from	To	Multiply by
	MASS PER UNIT VOLUME (INCLUDES DENSITY)	
kilogram per cubic meter (kg/m^3)	pounds per gallon (U.S.) (lb/gal)	8.345 406 E-03
kilogram per cubic meter (kg/m^3)	grams per cubic centimeter (g/cc)	1.000 000 E-03
	POWER	
watt (W)	Btu (International Table) per hour (Btu/hr)	3.412 141 E+00
watt (W)	calories per minute (cal/m)	1.434 034 E+01
watt (W)	erg per second (ergs/s)	1.000 000 E+07
watt (W)	horsepower (550 ft·lb f/s) (hp)	1.341 022 E-03
watt (W)	kilocalorie (thermochemical) per min (Kcal/min)	1.434 034 E-02
	VELOCITY	
meter per second (m/s)	foot per second (ft/s)	3.280 840 E+00
meter per second (m/s)	inches per second (in/s)	3.937 008 E+01
meter per second (m/s)	kilometers per hour (km/h)	3.600 000 E+00
meter per second (m/s)	miles (international) per hour (mph)	2.236 936 E+00
kilometer per hour (km/h)	miles (international) per hour (mph)	6.213 712 E-01
	VOLUME	
cubic meter (m^3)	acre foot (U.S. Survey)	8.107 085 E-04
cubic meter (m^3)	barrel (oil, 42 U.S. gallons)	6.289 811 E+00
cubic meter (m^3)	bushel (U.S.) (bu)	2.837 759 E+01
cubic meter (m^3)	cubic foot (ft^3)	3.531 466 E+01

To convert from	To	Multiply by
cubic meter (m^3)	gallon (U.S. dry) (gal)	2.270 207 E+02
cubic meter (m^3)	gallon (U.S. liquid) (gal)	2.641 720 E+02
cubic meter (m^3)	cubic inch (in^3)	6.102 376 E+04
cubic meter (m^3)	liter (l)	1.000 000 E+03
cubic meter (m^3)	ounce (U.S. fluid) (oz)	3.381 402 E+04
cubic meter (m^3)	pint (U.S. dry) (pt)	1.816 166 E+03
cubic meter (m^3)	pint (U.S. liquid) (pt)	2.113 376 E+03
cubic meter (m^3)	quart (U.S. dry) (qt)	9.080 829 E+02
cubic meter (m^3)	quart (U.S. liquid) (qt)	1.056 688 E+03
cubic meter (m^3)	cubic yard (yd^3)	1.307 951 E+00
cubic centimeter (cc, cm^3)	cubic inch (in^3)	6.102 374 E-02

VOLUME PER UNIT TIME (INCLUDES FLOW)

cubic meter per second (m^3/s)	cubic foot per minute (ft^3/min)	2.118 880 E+03
cubic meter per second (m^3/s)	cubic foot per second (ft^3/s)	3.531 466 E+01
cubic meter per second (m^3/s)	cubic inch per minute (in^3/min)	3.661 425 E+06
cubic meter per second (m^3/s)	cubic yards per minute (yd^3/min)	7.847 704 E+01
cubic meter per second (m^3/s)	gallon (U.S. liquid) per day (gpd)	2.282 446 E+07
cubic meter per second (m^3/s)	gallon (U.S. liquid) per minute (gpm)	1.585 032 E+04

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1.0 INTRODUCTION

This report is one of a series on the coal liquefaction technology, with particular reference to the estimation of the potentially adverse effects of pollutant stressors emanating from a hypothetical, standard-sized solvent refined coal (SRC) facility presumed to be located along the Wabash River in White County, Illinois. The Standards of Practice Manual (SPM) for the SRC process (1), issued earlier by Hittman Associates, served as a basis for evaluating the effects of SRC pollutants on all media.

Another objective was to provide substantial background information in the form usable for an Environmental Assessment Report (EAR) on the SRC technology. Thus, the wide-ranging scope of the inputs may create an impression of irrelevance to the major purpose of this report. Under these circumstances, the indulgence of the reader is requested, pending the appearance of the more concise Environmental Assessment Report.

The selection of the White County site for the hypothetical SRC facility is viewed as a useful construct in that three of the most important siting requirements are already fulfilled, as follows:

- Proximity to an abundance of water
- Proximity to an adequate supply of Illinois No. 6 coal
- Adequate distance from public lands and sensitive ecosystems.

This construct has further merit, in that the analyst is constantly challenged to sort out those aspects of potential importance (resulting either from the construction or the operation of the SRC facility) requiring little or no further baseline study, from those that will likely require more detailed study. For example, it should be relatively easy to estimate the potential environmental stresses stemming from the construction and operation of the SRC plant in relation to existing land use, water use, soil and geologic factors, and the state and local infrastructure. Of much greater difficulty is the estimation of the potential for groundwater contamination stemming from hazardous waste leachate, earthquake hazard, changes in local and regional precipitation patterns, and localized effects of air pollutants on soybean and other high-volume, high-dollar-value crops.

This report was written in full awareness of key questions relating to the necessary development of regulatory standards and goals. Coupled with the existing regulatory requirements are the emerging multimedia environmental goals (MEG) and the source analysis models (SAM/IA) currently being developed by the EPA/IERL-RTP (2). Both of these methodologies are discussed in Appendix I of this report.

Chapter 3 presents updated information on the quantities and characteristics of effluent constituents associated with the construction and operation of the SRC technology (plus the auxiliary units) in the multimedia context. These data served as a basis for evaluating the MEG and SAM/IA goals.

Chapter 4 describes the White County environment as it presently exists without the proposed SRC plant. The generic and site-specific environmental issues and constraints are also discussed.

Chapter 5 is essentially a generic discussion of recognized abiotic and biological interactions on pollutants with reference to air and water quality, water use, land use, and threatened and endangered species of animals and plants. Chapter 5 also addresses several useful strategies that should lead to the increased protection and allocation of resources should an SRC technology become a reality. More definitive environmental assessments will be provided in a future EAR report on the SRC technology.

Chapter 6 discusses pollutants of concern in terms of the volume and concentration of pollutants (both chemical and non-chemical) that are expected to emanate after treatment from the SRC plant. The relation of these pollutants to current environmental standards and goals is also discussed where and when appropriate.

Chapter 7 identifies needed research in terms of (1) the SRC technology, (2) environmental assessment and monitoring, and (3) the environmental sciences. These latter needs are essentially generic in nature, and are considered applicable to coal gasification and other coal conversion technologies.

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1. Hittman Associates, Inc. Standards of Practice Manual for the Solvent Refined Coal Liquefaction Process. EPA 600/7-78-091. EPA Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina, 1978. 353 pp.

2. Cleland, J.G. and G.L. Kingsbury. Multimedia Environmental Goals for Environmental Assessment. Vol. I, EPA-600/7-77-136a, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. 1977.

2.0 DESCRIPTION OF THE SOLVENT REFINED COAL LIQUEFACTION PROCESS AND EXISTING ENVIRONMENTAL REQUIREMENTS

2.1 Introduction

The basis for this study is a hypothetical commercial solvent refined coal (SRC) liquefaction facility which consumes 28,123 megagrams (Mg) of coal, which is equivalent to 31,000 tons (T) of Illinois No. 6 (Herrin) coal per day. The plant is presumed to be located on the Wabash River in White County, Illinois. This site was selected because of its proximity to large reserves of a process-compatible raw coal feed, the availability of an adequate water supply, and an expressed interest by the State of Illinois in coal conversion (1).

The SRC system (1) utilizes a non-catalytic direct-hydrogenation coal liquefaction process. It converts high-sulfur and -ash coal into clean-burning gaseous, liquid, or solid fuels. There are two basic system variations: (1) SRC-I, which produces a solid coal-like product of less than 1 percent sulfur and 0.2 percent ash; and (2) SRC-II, which produces low-sulfur fuel oil (0.2-0.5 percent sulfur) and naphtha product. Both system variations produce significant quantities of gaseous hydrocarbons, which are further processed in the SRC system to synthetic natural gas and liquefied petroleum gas products. Some constituents that are formed during the hydrogenation reaction are recovered as by-products. These include sulfur, ammonia, and phenol. This report is aimed primarily at the SRC-II system, which at this time seems to be the most promising alternative.

To facilitate an understanding of the basic components of the SRC system, a modular approach is taken. In the modular approach, the SRC-II system is subdivided into operations. Each operation is accomplished by carrying out a group of processes, a process being the smallest unit of the overall system. Auxiliary processes perform functions incidental to the functions of system operations. All processes may be represented visually by process modules, which display process input and output stream characteristics. Sets of process modules may be used to describe SRC system operations, the overall SRC system, or the entire coal liquefaction energy technology.

2.2 Description of the SRC System

The SRC-II system is divided into eleven system modules (1). These include coal preparation, hydrogenation, phase (gas) separation, solids separation, fractionation, hydrotreating, solidification, hydrogen generation, gas purification, cryogenic separation, and auxiliary facilities. The first six modules are considered basic system modules, while the remaining five are considered supporting operations. Figure 2-1 depicts the overall flow pattern for the SRC-II process, including both process and waste flow streams.

2.2.1 Coal Preparation Module

Coal preparation includes coal receiving, storage, reclaiming and crushing, cleaning, drying and pulverizing, and slurry mixing. These processes, excluding slurry mixing, are designed to clean and size-reduce the coal to levels acceptable for use in the SRC liquefaction process. The slurry mixing process mixes the processed coal with recycled process solvent prior to entering the hydrogenation reactor. Dryer stack gases, refuse, and wastewaters

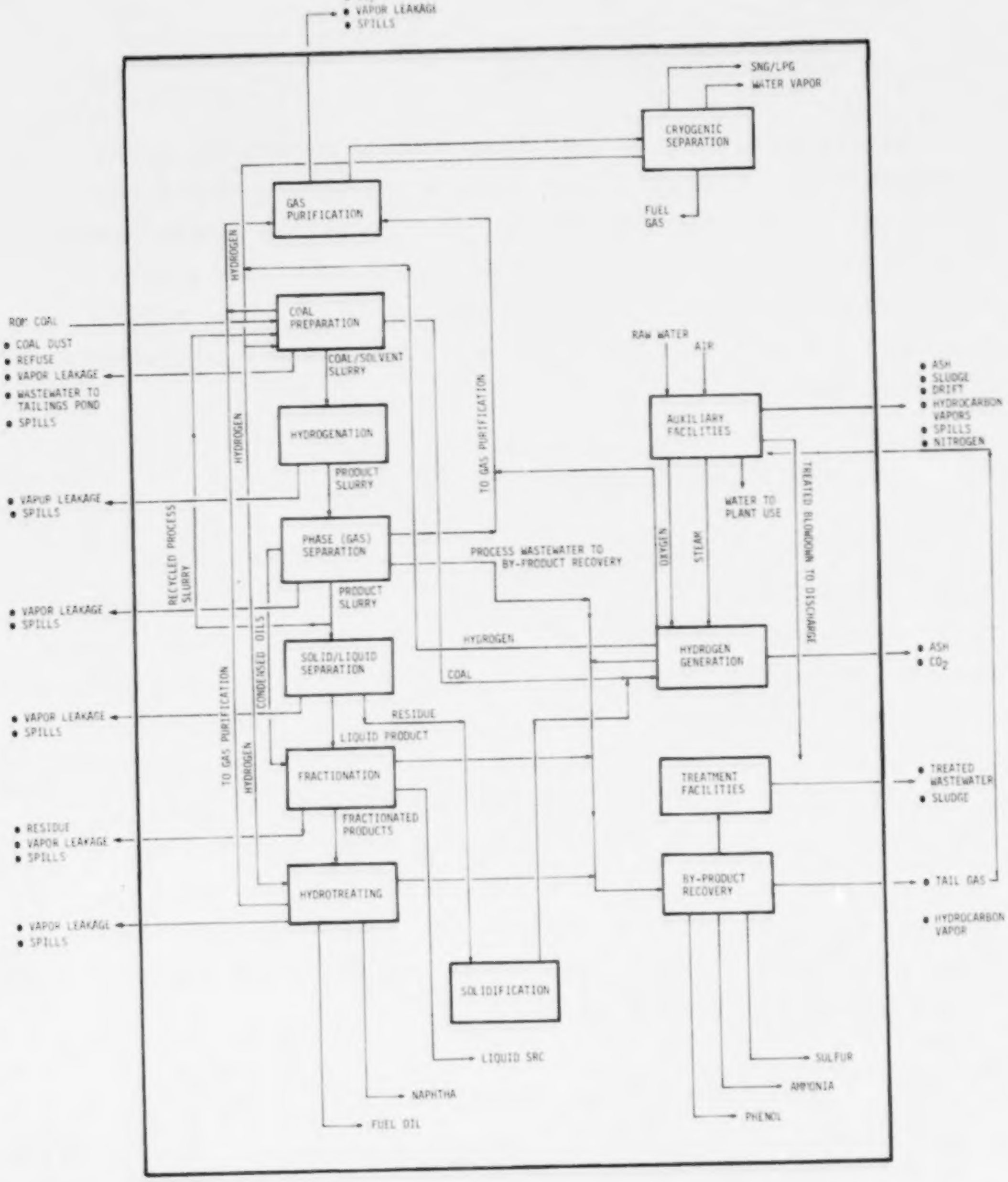
• CO2
• VAPOR LEAKAGE
• SPILLS
SNG/LPG
WATER VAPOR
CRYOGENIC SEPARATION
GAS PURIFICATION
FUEL GAS
HYDROGEN
ROM COAL
• COAL DUST
• REFUSE
• VAPOR LEAKAGE
• WASTEWATER TO TAILINGS POND
• SPILLS
COAL PREPARATION
COAL/SOLVENT SLURRY
HYDROGENATION
HYDROGEN
TO GAS PURIFICATION
RAW WATER
AIR
AUXILIARY FACILITIES
• ASH
• SLUDGE
• DRIFT
• HYDROCARBON VAPORS
• SPILLS
• NITROGEN
WATER TO PLANT USE
TREATED BLOWDOWN TO DISCHARGE
OXYGEN
STEAM
• VAPOR LEAKAGE
• SPILLS
PRODUCT SLURRY
RECYCLED PROCESS SLURRY
PHASE (GAS) SEPARATION
PROCESS WASTEWATER TO BY-PRODUCT RECOVERY
• VAPOR LEAKAGE
• SPILLS
PRODUCT SLURRY
CONDENSED OILS
SOLID/LIQUID SEPARATION
HYDROGEN
COAL
HYDROGEN GENERATION
• ASH
• CO2
• VAPOR LEAKAGE
• SPILLS
TO GAS PURIFICATION
HYDROGEN
RESIDUE
LIQUID PRODUCT
FRACTIONATION
TREATMENT FACILITIES
• TREATED WASTEWATER
• SLUDGE
• RESIDUE
• VAPOR LEAKAGE
• SPILLS
FRACTIONATED PRODUCTS
HYDROTREATING
BY-PRODUCT RECOVERY
• TAIL GAS
• HYDROCARBON VAPOR
• VAPOR LEAKAGE
• SPILLS
SOLIDIFICATION
LIQUID SRC
SULFUR
AMMONIA
NAPHTHA
PHENOL
FUEL OIL

Figure 2-1. SRC-II system overall flow diagram (1)

heavily laden with suspended solids constitute major wastes in this module.

2.2.2 Hydrogenation Module

Hydrogenation consists of a slurry preheater and a hydrogenation reactor. This module constitutes the key operation within the SRC system where coal is transformed into liquid products. All other subsequent operations focus on refining the products generated in this module. Flue gas represents the only significant waste discharged from the module.

2.2.3 Phase (Gas) Separation Module

There are a number of processes within the phase (gas) separation module, including: high-pressure separation, condensate separation, intermediate flashing, intermediate pressure condensate separation, and low-pressure condensate separation. These processes separate hydrocarbon vapors and other gaseous products from the hydrogenation reactor effluent slurry and direct the solids/liquid portion of the coal slurry to other processing areas. Process streams from the module are directed to gas purification, solids separation, and fractionation. Waste emissions include accidental and fugitive vapor discharges and material spills.

2.2.4 Solids Separation Module

The processes within the solids separation module include feed flashing and solids separation. These processes separate the residue (solids) stream from the liquid portion of the feed stream. The residue is routed to the solidification module to be prepared for gasification or disposal. No wastewater streams are discharged from this module under normal operations. Intermittent discharges include fugitive vapors and accidental material spills.

2.2.5 Fractionation Module

The fractionation module consists of a vacuum flash and an atmospheric distillation functioning to (1) separate the high-boiling liquid SRC product from lower-boiling fractions, (2) combine light streams for fractionation into light products, and (3) separate wash solvent for recycling to the solids separation module. Evacuation of the flash vessel may be accomplished by steam ejector, which produces a continuous wastewater stream, or vacuum pump, which produces a gaseous waste stream. Preheater flue gas constitutes the only other continuous waste stream. Intermittent discharges include fugitive vapors and accidental material spills.

2.2.6 Solvent Hydrotreating Module

The solvent hydrotreating module consists of hydrogen addition, catalytic reaction, flashing, oil-water separation, and stripping. Solvent hydrotreating involves the reaction of raw hydrocarbon streams with hydrogen to remove contaminants such as organic sulfur and nitrogen compounds, and to improve combustion characteristics. Flue gas from the solvent preheater and wastewater from an oil-water separator are the only continuous waste streams.

2.2.7 Solidification Module

The function of the solidification module in the SRC-II system is to cool the residue into a solid suitable as a feed to the gasifier. This function is accomplished by feeding the liquid residue onto a Sandvik belt cooler. The cooled solid residue is scraped off the belt with a knife and routed to gasification. Emissions from the solidification module include vapors and particulates from the belt cooling process. Also, a solid waste stream results from the disposal of residue in excess of gasifier requirements.

2.2.8 Gas Purification Module

Contaminated gases from phase (gas) separation and solvent hydrotreating modules are purified by acid gas removal. Contaminants removed include hydrogen sulfide, carbon disulfide, carbon dioxide, and carbonyl sulfide. The only continuous waste stream is the wastewater from the amine regenerator section of the acid gas removal unit. Intermittent wastewater streams are accidental spills and backwash of the amine filter. Atmospheric emissions include gas leakage from sumps and storage vents, and fugitive emissions during maintenance operations.

2.2.9 Cryogenic Separation Module

Gas from the purification module flows to a series of cryogenic units within this module, where the heavier hydrocarbon gases are cooled and condensed to form a liquid. The resulting liquid stream is charged to a fractionation tower where various hydrocarbon products are removed. The remaining gases are flashed and flow to another series of cryogenic units and a de-ethanizer column, where the liquid product is removed and overhead gases flow to another series of cryogenic units.

Purified gas is separated into hydrogen, synthetic natural gas, liquefied petroleum gas, and light oils in this module. Wastewater from light oil distillation is the only waste stream from this module.

2.2.10 Auxiliary Processes Module

Auxiliary processes include ammonia recovery, phenol recovery, sulfur recovery, oxygen generation, raw water treatment, cooling towers, steam and power generation, product and by-product storage, wastewater treatment, and hydrogen production. These processes recover by-products from waste streams, furnish utilities (steam, water, power), and furnish feed materials (oxygen, hydrogen). Major waste streams include wastewater from ammonia stripping towers; wastewater from the phenol extraction towers; off-gas from the sulfur recovery absorber; gaseous waste nitrogen from oxygen generation; sludges from raw water treatment; wastewater resulting from blowdown of cooling towers; flue gases and ash from steam and power generation; spills, fugitive vapors and dust from product and by-product storage; treated wastewater and sludges from wastewater treatment; and slag, spent catalyst, spent scrubbing solutions and flue gases from hydrogen production.

2.3 Existing Environmental Requirements

No federal regulations for air, water or solid wastes have yet been promulgated to address specifically the commercial SRC and related coal liquefaction technologies. There are, however, a number of federal regulations applicable to other industries that provide some insight into levels of control that might be required for liquefaction processes. These industries include coal mining, coal preparation and storage, and petroleum refining. The effluent limitations for refineries are functions of the overall size and the pollution potentials of the several unit processes. Conceivably, equitable effluent standards may be developed along these same lines for related coal liquefaction processes.

National emission standards for hazardous air pollutants are established in conjunction with EPA. Standards currently exist for mercury, beryllium, and asbestos. Although none of these is likely to affect SRC production, future standards for hazardous air pollutants may be applicable.

The characterization of solid waste materials leaving SRC conversion plants is incomplete. It is very possible that hazardous wastes are present. For this reason, subsequent discussions of solid waste disposal shall include hazardous waste disposal, although the need for such measures is not certain. In Appalachian coals, the trace elements zinc, cadmium, manganese, arsenic, molybdenum, and iron are reportedly contained within the mineral matter of coal, further suggesting caution in the disposal of solid and hazardous wastes (2). Guidelines for land use and ultimate disposal of solid wastes are not as advanced as the legislation governing emissions to air and water.

Not all constituents of the products, by-products, and wastes generated by the SRC process are known. The Toxic Substances Control Act of 1976 was established to provide regulation and testing of new and existing chemical substances that could cause unreasonable health and environmental consequences. Testing may be prescribed for cumulative or synergistic effects, carcinogenicity, mutagenicity, birth defects, and behavioral disorders. Should any SRC process components be characterized as toxic, the development of technology capable of isolating and disposing of those components will be necessary. The potential impact is difficult to assess because the characterization of the SRC process components, and the determination of the levels of occurrence of known toxicants in the various SRC waste streams, have not been quantified.

Table A-II-8 (Appendix II) shows 28 designated industries that must comply with the new PSD numerical increments. All sources in the country, regardless of their location, must also comply with new source performance standards (NSPS), expressed as emission requirements for the designated source category.

The existing NSPS limiting SO_2 emissions to 520 nanograms per joule input (1.2 pounds per million Btu) could probably be met by SRC-I and SRC-II. However, the more recent requirement for existing plants of about 260 nanograms of SO_2 per joule input could not be met by SRC-I without extreme cost penalties (3).

Table A-II-9 (Appendix II) lists the 65 classes of organics and inorganics for which the EPA was directed by the courts to establish the best available treatment technology (BAT) effluent limitations and guidelines, under a settlement agreement with the Natural Resources Defense Council. Industry is required to apply BACT and be in compliance by July 1, 1984. Should the EPA set a toxic standard (under Section 307(a)) instead of BACT, industry must comply within 1 to 3 years after the toxic standard is set.

2.3.1 Federal Requirements

2.3.1.1 Air Pollutants

The Clean Air Act Amendments of 1977 (PL95-95) substantially changed the conditions for obtaining permits for the construction of new and expanded stationary source facilities. These new amendments will require the development, interpretation, and submission of several kinds of data, increase the lead time required to obtain construction permits, and influence the development of industries within each state (4). National primary and secondary ambient air quality standards (NAAQS) for SO_2, particulates, CO, photochemical oxidants, hydrocarbons, and NO_x are shown in Table 81 of the Standards of Practice Manual for SRC Coal Liquefaction Processes (SPM) (1). New stationary source performance standards for coal preparation plants, petroleum liquid storage vessels, and fossil steam generating plants are shown in Table 82 of the SPM (1). Specific federal pollutant limitations for ambient air quality (EPA and OSHA) are shown in Table A-II-10 of Appendix II.

2.3.1.1.1 Designation of Attainment and Nonattainment Areas

Every state was required to submit to the EPA by December 6, 1977, a statement of the degree of attainment of air quality in each of their air quality control regions (AQCRs) for SO_2, NO_x, CO, total suspended particulate matter (TSP), photochemical oxidants, and hydrocarbon compounds. Any AQCR (or portion thereof) shown to possess air quality better than that promulgated in the NAAQS for SO_2 and TSP will be designated as a prevention of significant deterioration (PSD) or attainment area for these pollutants. Where the air quality is shown to be worse than the NAAQS, the area will be designated as a nonattainment area (NA). Thus, any area designated to PSD status within a given state will likely experience limited industrial development (4).

The Clean Air Act Amendments of 1977 stipulate interim rules for both the PSD and NA until the State Implementation Plans (SIPs) are revised. In certain cases, the new law exempts some sources from the PSD requirements. The states are required to complete their revisions of the SIPs by December 1, 1978. The 1977 amendments established three classes of clean air areas and set maximum allowable increases in levels of SO_2 and TSP (above baseline) for the Class I, Class II, and Class III areas, as shown in Table 2-1. The short-term increments in all classes may be exceeded once per year at each location. The new amendments immediately designated the following Class I areas (3):

- All international parks
- National wilderness areas
- National memorial parks larger than about 2,430 hectares.

TABLE 2-1. PSD PERMITTING AGREEMENTS (3)

	Class I	Class II	Class III (micrograms/m^3)[a]	NAAQS
SO_2 Annual	2	20	40	80
24-hour	8	91	182	365
3-hour	25	512	700	1,300[s]
TSP Annual	5	19	37	7,560[s]
24-hour	10	37	75	260,150[s]

[a] All 24-hour and 3-hour values may be exceeded once per year.
[s] Indicates a secondary standard.

State governors may redesignate any area to Class I status. Certain areas may be redesignated to Class III status, except those areas that are greater than about 4,047 hectares in size, as follows:

- Existing national monuments
- Primitive areas
- Recreation areas
- Wild and scenic river areas
- Wildlife refuges
- Lakeshores and seashores
- Future national parks and wilderness areas

Areas within Indian reservations may be redesignated only by the applicable Indian governing body.

2.3.1.1.2 Increment Limitations

The PSD increment limitations shown in Table 2-1 represent small percentages of the NAAQS concentrations for SO_2 and TSP, including allowable concentrations that exceed the level existing at the time of the first application for a permit in an area subject to PSD rules (i.e., the baseline air quality). The baseline air quality concentrations must include all projected emissions from any one of the 28 major industrial categories (shown in Table A-II-8) which began construction before January 6, 1975, but which did not go into operation by the time the baseline measurement of air quality was made (4). Emissions from any major facility that began construction after January 6, 1975, must be counted against the maximum allowable increment limitation for any PSD area. State governors are permitted to extend exemptions in determining compliance with the allowable PSD ambient increments when the following conditions prevail:

- Ambient concentrations are increased because of fuel conversion orders
- Increases resulting from construction or temporary emissions-related actions
- Increases resulting from conversion from natural gas to coal as a result of low supply
- Increases attributable to sources outside the United States.

2.3.1.1.3 Monitoring Requirements in Nonattainment Areas (NA)

Industries presently located in nonattainment areas, even though now in compliance, will be required to impose additional future controls to bring about areal compliance. Owners contemplating the construction of new facilities in NA will be required to submit baseline air quality monitoring data. Thus, detailed advance planning will be required.

Additional discussion relating to the following items is given in Appendix II, Tables A-II-11 and A-II-12:

- Monitoring and modeling requirements in PSD areas
- Sharing of PSD increments

- Visibility and other air quality values
- Nonattainment areas
- Principal EPA rulemaking deadlines.

2.3.1.2 Water Pollutants

Table 83 of the SPM (1) includes effluent standards and guidelines for several industries having operations similar to SRC liquefaction; these include coal preparation and storage facilities, and petroleum refineries. The Clean Water Act has established long-range national goals to limit point source effluent discharges into navigable waterways. The Act requires application of the best practicable control technology currently available (BPT) not later than July 1, 1977. By 1983 the Act requires the application of the best available control technology economically achievable (BACT) in order to meet the national goal of eliminating the discharge of all pollutants (i.e., zero discharge). Specific pollutant limitations for effluent standards (one-day maximums) are given in Table A-II-10 of Appendix II. Table 127 of the SPM (1) is shown on page 353 of the SPM, Appendix B.

2.3.1.2.1 EPA Effluent Guidelines

Under the Clean Water Act, the EPA has promulgated effluent guidelines to be met by various industries. For existing point source discharges other than publicly owned treatment works, the Act requires that the EPA establish effluent guidelines and new source performance standards (NSPS) for nonpoint source discharges (5).

EPA has proceeded in the promulgation of BPT, BACT, and NSPS on an industry-by-industry basis, subcategorizing each industrial category as necessary. Guidelines for new industrial categories have not yet been promulgated, although to date the EPA has established guidelines covering the bulk of domestic industrial activity.

Guidelines are promulgated on a mass discharge basis, limiting the discharge of regulated process wastewater pollutants according to the scale of industrial production, raw material usage, or similar parameter of individual industrial plant activity. For example, effluent guidelines of the textile industry are expressed in allowable milligrams of each process wastewater pollutant regulated per 1000 kilograms of textile product produced (6).

For each industrial category regulated, the EPA has published one or more development documents describing the industry, its pollutants and wastewater flows, and the process technologies considered in the establishment of BPT, BACT, and NSPS. Although the effluent guidelines are expressed as mass discharge units, they are derived from expected concentrations of process wastewater pollutants achievable by application of appropriate control technology. Further, most development documents report expected wastewater volumes associated with the point source discharges, expressed as volume of liquid per unit of industrial activity. Using the textile industry example, expected wastewater volumes are given in liters per 1000 kilograms of product. By dividing the mass discharge effluent limitation by the wastewater volume per unit of industrial activity, equivalent standards expressed as concentration units can be calculated (6):

$$\frac{\text{Limitation, in mg/unit of activity}}{\text{Waste Volume, in l/unit of activity}} = \text{mg/l}$$

Thus, it is simple to convert mass discharge limits to concentration limits for each process wastewater pollutant of each industrial category and subcategory.

In many instances, when the appropriate conversion of limitations to common concentration units is made, consistent limitation values result. In other instances and for many process wastewater pollutants, widely varying concentration values result (6).

2.3.1.2.2 Recent Amendments to the Clean Water Act

The 1977 amendments to the Federal Water Pollution Control Act (FWPCA), along with the 1972 amendments, set forth the principal mechanisms for the control of water pollution from industrial sources. For example, standards of performance for new source coal preparation plants and associated areas were issued in 1977. Limitations were established for point source discharges of wastewater after application of BACT, assuming that such discharges normally are acidic or alkaline prior to treatment. Allowable values for any one day, and averages of daily values for 30 consecutive days for discharges of process wastewater from facilities which recycle wastewater for use in processing are shown in Table 2-2.

From facilities which do not recycle wastewater for use in processing, there shall be no discharge of untreated wastewater into navigable waters.

Any excess water, resulting from rainfall or snow melt, discharged from facilities designed, constructed, and maintained to contain or treat the volume of water

TABLE 2-2. STANDARDS OF PERFORMANCE FOR NEW SOURCE COAL PREPARATION PLANTS (7)

	Maximum for Any One Day		Maximal Averages of Daily Values for 30 Consecutive Days	
Effluent Characteristics	Acidic	Alkaline	Acidic	Alkaline
TSS, mg/1	70.0	70.0	35.0	35.0
Iron (total)mg/1	3.5	3.5	3.0	3.0
Manganese (total) (mg/1)	4.0	NA	2.0	NA
pH	6-9	6-9	NA	NA

which would result from a 10-year, 24-hour precipitation event, shall not be subject to the limitations set forth in the NSPS.

Where the application of neutralization and sedimentation treatment technology results in an inability to comply with the manganese limitation set forth in the NSPS, the permit issuer may allow the pH level in the final effluent to be exceeded to a small extent in order that the manganese limitation will be achieved. In no case shall the pH exceed 9.5 (7).

Sections 301 and 304, Effluent Limitations and Guidelines, required the use of best practicable control technology (BPT) for the first phase of industrial cleanup. Approximately 85 percent of industrial dischargers met the July 1, 1977, deadline.

Under the new amendments (Clean Water Act of 1977, PL 95-217) three classes of pollutants were provided for the second phase of cleanup; these included toxic, conventional, and nonconventional pollutants.

The EPA must promulgate BAT regulations for any chemical added to the list of 65 classes of toxic pollutants as soon as practicable (see Table A-II-9). In this case, industry must comply not later than three years after the BACT regulation was set. But if the EPA should set a toxic standard instead of BACT, industry shall comply within one to three years after the toxic standard is set.

For conventional pollutants (i.e., BOD, DO, TSS) the EPA must set effluent limitations requiring best conventional pollutant control technology, and industry must comply by July 1, 1984. The level of pollutant control can be no less than BPT, and as high as BACT (5).

For all unconventional pollutants (i.e., those other than toxic or conventional) industry must comply with BACT no later than July 1, 1987. These controls are subject to strict waiver requirements.

Section 306 of the Clean Water Act provides for the development of standards of performance for new point source discharges, giving consideration to control technology, processes, and operating methods, among other alternatives.

Sections 307(b) and (c) require that pretreatment standards be promulgated for discharge of toxic substances and other pollutants into publicly owned treatment works. These standards would prevent the discharge of any pollutant known to be incompatible with such treatment works. Under the new amendments, localities may revise pretreatment requirements for toxic pollutants, particularly where the municipal treatment works removed all or part of the toxicants (5).

It appears that the weakest areas in the statutory control of toxic water pollutants include the following:

- Accidental spills
- Nonpoint sources of overland flows
- Urban stormwater runoff.

With regard to spills, further implementation of Section 311 of the Clean Water Act may strengthen controls in this area. With respect to nonpoint sources of overland flows (agricultural, silvicultural, and construction and mining runoff) and urban runoff, Section 208 programs will culminate in guidelines for controlling nonpoint sources. These 208 plans will be further developed by state and local authorities.

Other federal statutory requirements relating to toxic and hazardous water pollutants are described in Appendix II.

Any state already having promulgated other legislation which, in the opinion of the state and of the EPA is sufficient to allow the enforcement of a state hazardous waste program equivalent to that of the EPA, will be considered to satisfy the hazardous waste guidelines proposed by EPA.

2.3.1.3 Hazardous and Solid Wastes

On February 1, 1978, the U.S. Environmental Protection Agency promulgated, under Section 3006a, Subtitle C of the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) of 1976, a set of guidelines for state hazardous waste management programs. Hazardous wastes were found by the U.S. Congress to present special dangers to health; therefore, the states must develop programs to control them. In the event that any state chooses not to develop such a program, the EPA is required to do so. Hazardous wastes that are judged to have a significant impact on human health and the environment will be defined by the Section 3001 final regulations to be issued no later than April 21, 1978. Criteria and methods for identifying and listing hazardous wastes will also be issued in April, 1978. Those wastes identified as hazardous by these means are then included in the management control system constructed under Sections 3002 through 3006, and 3010 of the RCRA guidelines. The effective date for the regulations promulgated under Sections 3001 through 3005 is October 21, 1978. The six-month time period after final promulgation will be used to increase public understanding of the regulations, and to allow compliance by those covered by the regulations. During this same period, notifications required under Section 3010 may be submitted, and facility permit applications required under Section 3005 may be distributed for completion by applicants.

Section 3002 of the regulations presents the standards applicable to classes of generators of hazardous wastes, and requires the creation of a manifest system for tracking wastes from the generation point to the final site of storage, treatment, or disposal facility to which a permit was issued. Thus, the "cradle-to-the-grave" concept on which Subtitle C is based, includes the requirement that the regulatory agency has knowledge of the existence and movement of hazardous wastes through their entire life cycle. Those few states that already have a manifest system may be required to make their system consistent with the Federal one. The EPA expects to provide assistance to the states (i.e., software and other tools) in setting up the new manifest system.

Section 3003 addresses standards applicable to transporters of hazardous wastes and dealing with management of such wastes during the transport phase. Section 3004 addresses standards affecting owners and operators of hazardous waste storage, treatment, and disposal facilities. These standards provide the criteria against which EPA (or state) officials will review permit applications for on-site as well as off-site facilities operated by a generator or transporter of wastes. Generators and transporters who do not treat, store, or dispose of hazardous wastes do not need permits.

Section 3005 regulations define the scope, coverage, and requirements for permit application, as well as for the issuance and revocation of permits. Any possible overlaps between the state's issuance of permits to hazardous waste injection wells, and the issuance of hazardous waste permits under a state's existing program will be resolved by EPA.

Section 3010 requires that any person generating, transporting, owning, or operating a facility for storage, treatment, and disposal of hazardous wastes must notify the EPA or a state of this activity within 90 days of the EPA promulgation of regulations defining a hazardous waste (Section 3001).

2.3.2 State Requirements

2.3.2.1 Air Pollutants

Environmental requirements for air pollutants in states making up the major coal-bearing regions of the United States are sometimes more stringent than Federal requirements. Included in this section is a description of the highlights of the ambient air quality and emission standards for the following coal regions: Northern Alaska; Four Corners (Arizona, Colorado, New Mexico, and Utah); Eastern Interior (Illinois, Indiana and Kentucky); Fort Union - Powder River (Montana, North Dakota and Wyoming); Texas, and Appalachian (Ohio, Pennsylvania, and West Virginia).

2.3.2.1.1 Northern Alaska Region

The ambient air quality standards of Alaska are consistent with the NAAQS, (Table 81 of the SPM (1) appendix) except for the particulates primary standard (annual geometric mean of 60 compared to 75 micrograms/m^3), the lack of a standard for hydrocarbons, and the addition of a 30-minute maximum standard for reduced sulfur compounds of 50 micrograms/m^3. Emission standards for fuel-burning equipment and industrial processes in Alaska are shown in Table 86 of the SPM (1) appendix.

2.3.2.1.2 Four Corners Region

The ambient air quality standards for Arizona for particulates correspond to the NAAQS secondary standard of 60 micrograms/m^3 (AGM) and 150 micrograms/m^3 (24-hour maximum). The only other variance in Arizona versus the NAAQS standards is the annual maximum value for sulfur oxides (50 versus 80 micrograms/m^3) and the 24-hour maximum (260 versus 365 micrograms/m^3). The Arizona air quality goals and industrial emissions standards are given in Tables 88 and 89 of the SPM (1) appendix.

The State of Colorado has enacted standards of performance for stationary sources. Of these, the standards of performance for petroleum refineries are probably most indicative of future legislation relevant to the SRC technology. These standards are reviewed in Table 91 of the SPM

(1) appendix. Other relevant Colorado legislation pertains to oil-water separators similar to those used in SRC pilot plants. One or more of the following vapor loss controls is required: a solid cover, a floating roof, a vapor recovery system, or special equipment which can demonstrate equal or superior efficiency.

The State of New Mexico is presently the only state that has promulgated emissions standards applicable to coal conversion facilities, specifically coal gasification plants. Stacks at least ten diameters tall and equipped with enough sampling ports and platforms to perform accurate sampling are required. Particulate emissions requirements exist for briquet-forming areas, coal preparation areas, and the gasification plant itself - with an additional requirement for gas-burning boilers. Limits have been placed on dischargeable concentrations of sulfur, hydrocarbons, ammonia, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, carbon disulfide, and carbon oxysulfide as well. These limits are compiled in Table 105 of the SPM (1) and are stringent compared with those of the other coal-producing states. However, a review of New Mexico air laws pertaining to petroleum refineries reflects an interest in environmental preservation, not a distrust of new technology. Emissions standards for ammonia and hydrogen sulfide, for example, are the same for both industries. In fact, refineries have additional limits on mercaptan and carbon monoxide not presently included in gasification legislation. These requirements, as well as the New Mexico Ambient Air Quality Standards, are presented in Table 106 of the SPM (1) appendix. The ambient air criteria for heavy metals and the difference in dischargeable carbon monoxide concentrations between new and existing refineries are worthy of note. The ambient air quality standards of New Mexico include a heavy metals standard of 10 micrograms per

m^3, and a 0.003 ppm standard for hydrogen sulfide. The New Mexico standards for the 24-hour maximum for particulates and sulfur dioxide are somewhat lower than those for the NAAQS; all others are very similar.

The State of Utah has no ambient air or new source standards at this time. Current federal standards are applicable. The Utah Air Conservation Regulations note that the Utah Air Conservation Committee and the State Board of Health do not agree with most of the federal standards. There is no indication of the types of standards these organizations favor. State emissions standards have been set for particulates requiring 85 percent control. Sulfur emissions must meet federal ambient and new source standards, as shown in Tables 81 and 82 of the SPM (1) appendix.

2.3.2.1.3 Eastern Interior Region

The site for the hypothetical SRC plant considered in this study is located along the Wabash River in White County, Illinois. This state has promulgated both air quality standards, and emission standards and limitations for stationary sources. The Illinois air quality standards are the same as the NAAQS standards. The Illinois performance standards for stationary sources are shown in Table 96 of the SPM (1) appendix. The Illinois stationary source standards not only address the six regular criteria pollutants of the NAAQS, but also visible emission standards and sulfuric acid mist. Also addressed are organic material storage, loading, organic material-water separation, pumps and compressors, other discharges of organic material to the atmosphere, waste gas disposal, vapor blowdown, and the clean-up and disposal of organic materials. These standards are considered to be among the most comprehensive in the coal-producing states.

In addition to legislating ambient air quality standards, Indiana has laws controlling the storage and handling of volatile hydrocarbon liquids. A vapor recovery system, floating roof, or alternative system which meets approval of the proper state agencies is required. Volatile organic liquid-water separators require either a solid cover or one of the vapor control methods required for storage systems, essentially analogous to the Illinois standards. The air quality standards of Indiana are similar to the NAAQS standards.

The State of Kentucky air quality standards are similar to the NAAQS, except that standards were included for hydrogen sulfide (14 micrograms/m^3 one-hour maximum), gaseous HF (2.86 micrograms/m^3, 24-hour maximum), and total primary fluorides of 80 ppm (30-day average). Kentucky also has issued standards of performance for petroleum refineries, as shown in Table 101 of the SPM (1) appendix.

2.3.2.1.4 Fort Union - Powder River Region

The State of Montana has adopted the federal new source performance standards (see Table 82 of the SPM (1) appendix) to supplement its own ambient air quality standards. The annual arithmetic mean concentration of SO_x, and the total suspended particulate annual geometric mean of the Montana air quality standards are similar to the NAAQS. However, Montana has promulgated standards for H_2S, fluorides, settled particulates, lead, reactive sulfur (SO_3), suspended sulfate and sulfuric acid mist, as shown in Table 103 of the SPM (1) appendix.

Table 108 of the SPM (1) appendix shows the ambient air quality standards of North Dakota. These have been established in accordance with the state air quality guidelines which call for preservation of the health of the general public, plant and animal life, air visibility, and natural scenery. The guidelines also require that ambient air properties shall not change in any way which will increase corrosion rates of metals or deterioration rates of fabrics. Additionally, emissions restrictions from industrial processes exist for particulates and sulfur oxides. For particulates, North Dakota requires the use of the Arizona equation governing process industries in that state. Sulfur dioxide emissions are limited to 1.3 micrograms per joule heat input from coal.

Four of the six regular criteria pollutants of the Wyoming ambient air quality criteria (CO, hydrocarbons, NO_x and photochemical oxidants) are identical to the NAAQS, as shown in Table 82 of the SPM (1) appendix. Table 125 of the SPM (1) appendix shows the Wyoming emission standards that are largely applicable to fossil fuel burning sources. Additional requirements have been issued governing hydrocarbon storage and handling. Waste disposal combustion systems for vapor blowdown or emergency situations are to be burned in smokeless flares. Pressurized tanks, floating roofs, or vapor recovery systems are required for the storage of hydrocarbons.

2.3.2.1.5 Texas Gulf Region

The ambient air quality standards of the Texas coal-producing region are identical to the NAAQS for all six of the regular criteria pollutants. Texas has imposed additional ambient standards for hydrogen fluoride gas, net ground-level concentrations for emissions of H_2S, sulfuric acid and particulates, as shown in Table 118 of the SPM (1) appendix. Emissions limits for fossil fuel steam generators were also issued for SO_x, NO_x and particulates, as shown in

Table 118 of the SPM (1) appendix. The emission rates for SO_x and particulates are both functions of the effective stack height. Visibility requirements prohibit exceeding 20 percent opacity; these limits apply to five-minute periods and do not include opacity resulting from uncombined water mists.

2.3.2.1.6 Appalachian Region

The ambient air quality standards of Ohio are shown in Table 110 of the SPM (1) appendix. Ohio standards for the storage of hydrocarbons are comparable to those in other coal-producing states. Carbon monoxide emissions from the petroleum refinery processes must pass through an afterburner prior to discharge, while photochemical oxidants must be incinerated to a minimum of 90 percent oxidation prior to discharge to the atmosphere. Industrial process emission standards promulgated for particulates, SO_x, NO_x, hydrocarbons, CO, and photochemical oxidants may be applicable to coal conversion technologies. Ohio has established air quality priority zones; these presently do not meet EPA standards for SO_x, NO_x, and particulates. The SO_x emission limit is a mathematical function of the total emission discharge, while the limit of particulate emissions is a function of the process throughput.

The ambient air quality standards of Pennsylvania relate to lead, H_2S, fluorides, and settled particulates, as shown in Table 113 of the SPM (1) appendix. Industrial emission standards require a vapor recovery system for hydrocarbon loading equipment, and a floating roof for the hydrocarbon-water separator storage tanks.

The ambient air quality standards of West Virginia are identical to the six regular criteria pollutants of the

NAAQS. Regulations for coal preparation, drying and handling, and those for manufacturing processes are shown in Table 121 of the SPM (1) appendix.

2.3.2.2 Water Pollutants

Water quality standards of the coal-producing states that may affect future commercial SRC operations are highlighted here. The several factors that are determinate to the establishment of standards applicable to state waters of all classifications are shown in Table 2-3.

TABLE 2-3. FACTORS IN THE ESTABLISHMENT OF WATER QUALITY STANDARDS IN COAL-PRODUCING STATES

Region and State	Factors
Northern Alaska	Beneficial uses
Four Corners:	
Arizona	Beneficial uses
Colorado	NA
New Mexico	Stream (use) classification
Utah	Stream (use) classification
Eastern Interior:	
Illinois	Beneficial uses, mixing zone
Indiana	Beneficial uses, mixing zone
Kentucky	Stream (use) classification
Fort Union-Powder River:	
Montana	Beneficial uses
North Dakota	Beneficial uses
Wyoming	Beneficial uses
Appalachian:	
Ohio	Beneficial uses, mixing zone
Pennsylvania	Stream (use) classification
West Virginia	Stream (use) classification

2.3.2.2.1 Effluent Standards of the States

In contrast to the federal effluent guidelines which apply to specific industrial categories, the state numerical effluent standards for the seven coal-producing states (Table 2-4) apply equally to all point source discharges. In some states, the effluent standards are applicable only for discharges to selected bodies of water. Table 2-4 shows the coal-producing states that had issued numerical effluent standards for specific pollutants as of late 1976.

2.3.2.2.2 Illinois Effluent Standards

Both the federal and the Illinois effluent criteria are based on the capability of conventional treatment technology to achieve a given quality of industrial discharges. However, Illinois effluent standards (as of 1976) differ from that of the U.S. EPA in that they apply equally to all dischargers, irrespective of industrial category. Furthermore, the Illinois standards shown in Table 2-4 are absolute standards that must be met without subtracting background concentrations found in the intake waters (9). Notwithstanding this condition, the intention of these regulations is not to require users to clean up contamination caused essentially by upstream sources, or to require treatment when only traces of contaminants are added to the background. Compliance is therefore not required when effluent concentrations in excess of the standards result entirely from influent contamination, evaporation, and/or the incidental addition of traces of materials not utilized or produced (10). Compliance with the numerical effluent standards shall be determined on the basis of 24-hour composite samples. In addition, no contaminant shall at any time exceed five times the numerical standard prescribed by the effluent standards (10). Should it be found by the

TABLE 2-4. NUMERICAL EFFLUENT STANDARDS OF COAL-PRODUCING STATES

Pollutant	Eastern Interior		Ft. Union-Powder River		Four Corners	Appalachian	
	Illinois	Kentucky	Montana	North Dakota	Colorado	Maryland	Virginia
	(Numerical standard expressed as mg. per liter, total)						
Arsenic	0.25	–	Avg./d. 0.01[a] Max. 0.016[a]	–	–	–	–
Barium	2.0	–	–	–	–	–	–
BOD					25(7 day avg.) 30(30 day avg.)		
Cadmium	0.15	–	Avg./d. 0.01[a] Max. 0.01[a]	–	–	–	–
Chromium	0.30(hex.)	–		–	–	–	–
Copper	1.0	–	Avg./d,0.05-0.09[b] Max.,0.09-0.18[b]	–	–	–	–
Cyanide	0.025	–	–	–	–	–	–
Fluoride	15.0	–	–	–	–	–	–
Iron	2.0	–	Avg./d,0.3-1.3[b] Max.,1.3-2.2[b]	–	–	–	–
Lead	0.100	–	Avg./d,0.03-0.10[b] Max.,0.05-0.10[b]	–	–	–	–
Manganese	1.0	–	–	–	–	–	–
Mercury	0.0005	–	Avg./d,0.001[b] Max.,0.001[b]	–	–	–	–
Nickel	1.0	–	–	–	–	–	–
Oil	15.0	–	–	–	10.0(7 day avg.)[c] 10.0(30 day avg.)[c]	10.0	–
pH	5-10	6-9(7 day avg) 6-9(30 day avg)	–	6-9	6-9(7 day avg.) 6-9(30 day avg.)	6.0-8.5[d]	6.0-8.5[e]
Phenols	0.30	–	–	–	–	–	–
Selenium	1.0	–	–	–	–	–	–
Silver	0.10	–	–	–	–	–	–
Total Dissolved Solids	750-3500	–	–	–	–	–	–
Total Suspended Solids	5-15[f]	45(7 day avg.) 30(30 day avg.)	–	30[g]	45(7 day avg.) 30(30 day avg.)	[illegible][d]	[illegible][h] [illegible][h]
Zinc	1.0	–	Avg/d,0.01-0.3[b] Max.,0.2-1.0[b]	–	–	–	0.1[i]

[a] For Clark Fort River only.

[b] For segments of Clark Fork River.

[c] There shall be no visible sheen.

[d] Effluent limitation.

[e] For the entire Chickahominy watershed above Walkers Dam.

[f] Depends on body of water being discharged to.

[g] Municipal wastes.

[h] For the Rappahannock River Basin above proposed Salem Church Dam.

[i] Applies to all bodies of water.

Illinois Pollution Control Board that a given discharge was in violation of the effluent standards, and that such a violation was caused by the cumulative effect of more than one source, several sources may be joined in an enforcement or variance proceeding and measures for necessary effluent reductions will be determined on the basis of technical feasibility, economic reasonableness, and fairness to all discharges (10).

The U.S. Environmental Protection Agency delegated authority to the State of Illinois on October 23, 1977, to issue effluent discharge permits under provisions of the National Pollution Discharge Elimination System (NPDES). Thus, Illinois is now responsible for issuing all NPDES permits, and for bringing initial enforcement actions for permit violations, except for those concerning agencies and instrumentalities of the federal government.

2.3.2.2.3 State Water Quality Standards

Numerical water quality standards of the various coal-producing states may be more stringent than those of the EPA criteria for specific pollutants. By the same token, specific standards of a state may be one or more orders of magnitude higher than the EPA criteria for the same pollutants. The latter condition is illustrated by the fact that the Illinois standards for arsenic, manganese, phenol, and selenium are 10, 10, 100, and 100 times greater, respectively, than the EPA criteria. In a similar vein, the Kentucky standards for ammonia (as N), cadmium, and mercury are 100, 125, and 10 times greater, respectively, than the EPA criteria. In several states, the general practice is to provide supplemental criteria for specific numerical and non-numerical standards relative to the identified water classification (e.g., swimming, fishing, and domestic water supply uses).

With respect to toxic and hazardous water pollutants, non-numerical standards have been proposed by Arizona, Colorado, and Utah (Four Corners Region); Montana, North Dakota, South Dakota, and Wyoming (Fort Union-Powder River); Kentucky, Ohio, Virginia, and West Virginia (Appalachian Region). These standards are listed in Appendix II, Table A-II-13.

Numerical standards for toxic substances have been issued by Illinois (Eastern Interior region), Montana (pegged to bioassay and Public Health Service Drinking Water Standards), Indiana (pegged to Drinking Water Standards of USPHS), and Texas (ditto Montana). The State of Alaska has proposed neither numerical nor non-numerical standards for toxic and hazardous substances.

The detailed water quality standards for the coal-producing states are shown alphabetically in Appendix B of the SRC Standards of Practice Manual (1), starting on page 300.

2.3.2.2.4 State Hazardous and Solid Waste Regulations

Requirements promulgated by the EPA for state hazardous waste management programs were discussed earlier in this section. Seventeen coal-producing states have issued stipulations for some form of hazardous and solid waste management, as shown in Table 2-5. Thus, among the 17 coal-producing states listed, 14 have provided some type of statutory control over hazardous waste disposal operations. Among these states, Ohio, North Dakota, and Utah have explicit monitoring requirements for types of waste disposal operations. In view of the fact that the potentially vast amounts of solid wastes produced by coal conversion technologies, through compliance with air quality standards, must be disposed of on land, it is apparent that there is an equally vast potential for the degradation of local surface and groundwater systems near these disposal sites by the inorganic and organic leachates.

TABLE 2-5. EXISTING STATE REQUIREMENTS FOR HAZARDOUS AND SOLID WASTES

Coal Region and State	Hazardous Waste Controls	Permit Requirement	Approval	Design Criteria & Standards	Monitoring Requirements
Northern Alaska	no	yes	no	no	no
Eastern Interior:					
Illinois	yes	yes	no	yes	no
Indiana	yes	yes	no	no	no
Kentucky	yes	yes	no	yes	no
Four Corners:					
Arizona	yes	no	yes	no	no
Colorado	yes	yes	no	yes	no
New Mexico	no	yes	no	yes	no
Utah	yes	no	yes	no	yes
Fort Union-Powder River					
Montana	yes	no	notice	yes	no
North Dakota	yes	yes	no	yes	yes
Wyoming	yes	no	yes	yes	no
Appalachian					
Maryland	no	no	no	yes	no
Ohio	yes	yes	no	yes	yes
Pennsylvania	yes	yes	no	yes	no
Virginia	yes	yes	yes	yes	no
West Virginia	yes	yes	no	yes	no
Texas	yes	yes	manifest	yes	no

In North Dakota, the Department of Health may impose any reasonable conditions upon a permit to construct a land disposal site, including the following:

- Sampling, testing, and monitoring facilities
- Trial operation and performance testing.

North Dakota has stipulated standards of performance for the following types of disposal operations:

- Sanitary landfills
- Construction and demolition disposal sites
- Incinerators
- New and unique methods of disposal
- Hazardous wastes

The monitoring standards presently apply to sanitary landfills, and sites handling construction and demolition wastes.

The standards for disposal of hazardous wastes shall be met by the owner of such wastes. However, the state may provide technical assistance to the owner for the storage, transportation, and disposal of hazardous wastes. North Dakota defines hazardous wastes as those substances which singly, or in combination, exhibit a substantial present or potential hazard to human health or living organisms because of the following factors:

- Nondegradability
- Persistence in multimedia
- Biomagnification potential
- Lethality
- Ability to produce detrimental cumulative health and ecological effects.

The State of Ohio defines hazardous wastes as those substances which singly, or in combination, pose a significant present or potential threat or hazard to human health or to the environment, because of the following factors:

- Flammability
- Explosiveness
- Reactiveness
- Corrosiveness
- Toxicity
- Infectiousness
- Carcinogenicity
- Bioconcentrative potential
- Persistence in multimedia

- Potential lethality

- Action as an irritant or sensitizer.

Under the requirements promulgated by the Ohio Department of Health for sanitary landfill operations, there is an explicit requirement that the operator shall install such a number of monitor wells... as the Health Commissioner deems necessary to determine the effect of the facility upon the quality of groundwater (11). Each monitor well shall be sampled semi-annually for chlorides, COD, TOC, TDS, and methylene blue active substances. More frequent sampling and sampling for additional substances may be required if a substantial threat of water pollution exists. Specific instructions were issued concerning the eventual detection of leachate on the disposal site. Hazardous waste cannot be accepted at sanitary landfills. The monitoring wells must be maintained by the operator for three years after closure.

2.3.2.2.5 Illinois Land Disposal Criteria

The Illinois EPA (IEPA) stated in Rule 310(b) of the Solid Waste Rules and Regulations (Chapter 7 of the Environmental Protection Act) that hazardous wastes or liquid wastes and sludges may be accepted at a sanitary landfill only if authorized by permit. Thus, the IEPA can issue a supplemental permit allowing sanitary landfills to deviate from the applicable rules.

The IEPA requires that the applicant for a supplemental permit must submit information on the following (12):

- Type, consistency, and physical/chemical properties of the special or hazardous waste

- Quantity
- Method of disposal.

The IEPA stipulates procedures for analysis of specific inorganics and organics, by use of their landfill simulation leaching test. All known organic components of the waste should be determined if their concentrations exceed 0.1 percent (1000 ppm) of the total waste volume. Table 2-6 lists the minimum number of inorganics (8), organics (2), and radioactivity (alpha emitters) to be assayed. The assumption is made that the waste generator is aware of his usage of beryllium, selenium, antimony, or other potentially hazardous chemicals, and that the waste will be analyzed for components used in the process by which the waste originates.

The IEPA has specified absolute permissible maximum water soluble waste chemical (inorganics) concentrations for disposal at any of Type I, II, or III disposal sites (see Table 2-7).

The Type I site will receive waste displaying a high ingestion toxicity (based on the Sax rating), and thus very hazardous. The criteria for the Type I site require that it be buffered by at least 3.04 meters of soil having a coefficient of permeability not greater than 1×10^{-8} cm/sec, or not less than 3.04 meters of soil which can provide containment for 500 years (12). The Type II site must provide a containment life for less hazardous substances of 250 yeras. The Type III site must provide a containment life for municipal refuse of 100 years. Liquid special wastes may be placed into any of the three site types if the liquid is subjected to vertical and horizontal containment. Acceptable methods for disposing toxic and hazardous wastes in Illinois are shown in Table 2-8.

TABLE 2-6. ANALYSIS CHART FOR WASTE GROUPS (15)

	Parameter										
Waste Group	Arsenic	Cadmium	Chromium[a]	Copper	Cyanide[b]	Lead	Mercury	Nickel	Phenols	Zinc	Alpha Radiation[c]
Metals		X	X	X	X	X	X	X	X	X	X
		X	X	X	X	X		X		X	
		X	X	X	X	X		X		X	
Chemicals		X	X	X	X	X	X	X	X	X	
	X	X	X	X	X	X	X	X		X	X
Chemical Specialties	X	X	X	X	X	X	X	X	X	X	
Food											
General Manufacture	X	X	X	X	X	X	X	X	X	X	
Mining	X	X	X	X		X	X	X		X	X
Service Industries		X	X	X		X		X		X	
	X			X			X				
	X				X			X			X
		X	X			X	X	X			
Utilities		X	X	X		X	X	X		X	
											X
	X	X	X	X	X	X	X	X		X	X
Wholesale, Retail Trade		X	X	X		X	X	X	X	X	

[a] Total soluble chromium.

[b] "Free" cyanide per modified Leibeg method (ASTM).

[c] Measured from waste as received (unfiltered) in pCi/l.

Note: As more data become available, it is likely that this analysis chart will be expanded in terms of minimum required parameters and lengthened relative to industry specific analyses.

TABLE 2-7. ABSOLUTE PERMISSIBLE CONCENTRATIONS OF SOLUBLE INORGANICS AT DISPOSAL SITES IN ILLINOIS (12)

Soluble Inorganics[a]	Type of Disposal Site, and Limiting Concentration (ppm) Type I	Type II	Type III
As	500	75	25
Cd	500	75	25
Cr[b]	1,000	150	50
CN[c]	500	75	25
Cu	1,000	150	50
Hg	500	75	25
Ni	500	150	50
Pb	500	150	50

[a] Where soluble concentrations exceed limitations, a waste may receive pretreatment to insolubilize excess concentrations.

[b] Total soluble Cr.

[c] Total soluble cyanide (CN^-).

TABLE 2-8. ACCEPTABLE DISPOSAL METHODS (12)

Waste property	Type of site I	II	III	Disposal method[a] A	B	C	D
Highly acidic	-	-	-	-	-	-	-
Moderately acidic	-	-	-	-	-	-	-
Low acidity	X[b]	X	X	X	X	X	X
Highly alkaline	X	X	X	-	X	X	X
Moderately alkaline	X	X	X	X	X	X	X
Low alkalinity	X	X	X	X	X	X	X
High volatility	X	X	-	-	X	X	X
Moderate volatility	X	X	-	-	X	X	X
Low volatility	X	X	X	X	X	X	X
High toxicity (dermal)	X	X	-	-	X	X	X
Moderate toxicity (dermal)	X	X	-	X	X	X	X
Low toxicity (dermal)	X	X	X	X	X	X	X

(continued)

TABLE 2-8. (continued)

	Type of site			Disposal method[a]			
Waste property	I	II	III	A	B	C	D
High toxicity (inhalation)	X	X	–	–	X	X	X
Moderate toxicity (inhalation)	X	X	–	X	X	X	X
Low toxicity (inhalation)	X	X	X	X	X	X	X
High toxicity (oral)	X	–	–	X	X	X	X
Moderate toxicity (oral)	X	X	–	X	X	X	X
Low toxicity (oral)	X	X	X	X	X	X	X
Radioactive	–	–	–	–	–	–	–
Reactive	X	X	–	–	–	–	X
Explosive	–	–	–	–	–	–	–

[a] Note: A = Direct Landfill; B = Subsurface Injection; C = Surface Adsorption; D = Consignment Burial

[b] X – Indicates permittable disposal site or method of disposal

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3.0 POLLUTANT DISCHARGE LEVELS

This section characterizes the emissions and effluents which are expected from a conceptualized SRC plant producing approximately 7,950 m^3/day of syncrude product. The plant is assumed to be operating in the SRC-II mode and discharges are based upon the design outlined in the Standards of Practice Manual (1). It is important to keep in mind that the basis for the determination of emissions and effluents is a conceptualized design. Advances in technology, determination of the inapplicability of a specified treatment system, etc., may modify the design and consequently alter the nature and the quantities of discharges to the environment.

Several discharged streams have not been characterized to date. In these cases, we have made a first approximation based on data from similar industries, process development units, or bench scale assays. We have assumed that the plant is operating with Illinois #6 coal as characterized in Table 3-1 (A and B).

3.1 Air Emissions

The SRC process is, for the most part, an enclosed and pressurized system. Consequently, air emissions during regular plant operations are expected to arise primarily from auxiliary parts of the system, such as the cooling towers, boilers, acid gas treatment, hydrogen generators, sulfur recovery, and dryers, and from coal feed and coal feed products. Waste streams to air should be limited to leaks in pump seals, valves, joints, and flanges and to product handling and storage. These process-related emissions should be monitored in the plant as part of the industrial hygiene program.

TABLE 3-1. CHARACTERIZATION OF ILLINOIS NO. 6 COAL (2)

A. Minor Constituents (ppm)

Name	Symbol	Number of Individual Coal/ Analysis	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range	Number of "Less Than" Values
Aluminum	Al	44	13,500.	13,200.	3,070.	10,000-30,400	
Antimony	Sb	44	0.98	0.67	1.03	0.20-4.9	
Arsenic	As	44	5.9	4.1	6.9	1.0-32.0	
Barium	Ba	29	111.	78.	135.	5.0-750.0	
Beryllium	Be	44	1.5	1.4	0.69	0.70-3.9	
Boron	B	35	135.	126.	48	34-230	
Bromine	Br	44	15.	13.	7.9	1.8-52.0	
Cadmium	Cd	25	4.	0.69	13.3	0.50-65.0	
Calcium	Ca	44	7,690.	6,480.	5,000.	2,100-26,700	
Cerium	Ce	29	13.	12.	5.8	4.4-27.0	
Cesium	Cs	29	1.2	1.1	0.60	0.60-3.6	
Chlorine	Cl	44	1,600.	900.	1,600.	100-5,400.0	
Chromium	Cr	44	20.	18.	10.	7-60	
Cobalt	Co	44	6.6	5.9	3.1	2.5-15	
Copper	Cu	44	13.	13.	4.	6.0-26	
Dysprosium	Dy	29	1.0	1.0	0.26	0.57-1.8	
Europium	Eu	29	0.25	0.24	0.065	0.19-0.40	
Fluorine	F	44	63.	61.	18.	42.0-120.0	
Gallium	Ga	44	3.1	3.0	0.67	1.6-4.5	
Germanium	Ge	44	5.6	3.7	5.3	<20-26	10
Hafnium	Hf	29	0.52	0.48	0.21	0.20-1.1	
Indium	In	29	0.14	0.12	0.058	<0.10-0.23	11
Iodine	I	29	1.9	1.6	1.2	<1.0-5.8	8
Iron	Fe	44	18,600.	17,600.	5,900.	4,500-35,000	
Lanthanum	La	29	7.0	6.8	2.0	4.3-12.0	2
Lead	Pb	44	27.	14.	37.	1.10-210.0	2
Lutetium	Lu	29	0.08	0.07	0.027	0.02-0.15	
Magnesium	Mg	44	510.	490.	160.	200-1,110	
Manganese	Mn	44	53	44	34	13-180.0	
Mercury	Hg	44	0.18	0.16	0.10	0.04-0.52	
Molybdenum	Mo	44	9.2	7.3	6.0	<1.0-29.0	1
Nickel	Ni	44	22.	21	8.	12-42.0	
Phosphorous	P	44	45.	33	44.	<10.0-260	5
Potassium	K	44	1,700.	1,700.	270.	1200-2400	
Rubidium	Rb	29	16.	15.	6.7	7.0-42.0	
Samarium	Sm	29	1.2	1.1	0.58	0.78-3.8	
Scandium	Sc	44	2.6	2.6	0.67	1.4-4.1	
Selenium	Sc	44	2.2	2.0	1.2	1.2-7.7	
Silicon	Si	44	26,800.	26,400.	4,945.	18,900-46,300	
Silver	Ag	11	0.03	0.03	0.01	0.02-0.06	
Sodium	Na	44	660.	510.	460.	150-2,000	
Strontium	Sr	29	36	31	24	<10.0-130.0	2
Tantalum	Ta	29	0.16	0.15	0.063	0.10-0.30	
Thallium	Tl	24	0.67	0.59	0.32	0.12-1.3	
Thorium	Th	29	2.2	2.1	0.66	1.2-3.8	
Tin	Sn	16	4.7	0.94	9.0	<0.40-30	10
Terbium	Tb	24	0.17	0.15	0.098	0.04-0.45	
Titanium	Ti	44	700.	640.	170.	500.0-1,500	
Tungsten	W	29	0.70	0.55	0.52	0.04-2.1	
Uranium	U	29	1.6	1.3	1.0	<0.50-4.5	2
Vanadium	V	44	33	31	9.7	17.0-55.0	
Ytterbium	Yb	29	0.54	0.51	0.16	0.27-0.89	
Zinc	Zn	44	420.	120.	990.	13.0-5,300	
Zirconium	Zr	35	52.	46.	28.	16.0-120.0	

(continued)

TABLE 3-1. (continued)

B. Major Constituents (percent)

Name	Number of Individual Samples Analyzed	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range
Air-dry loss (%)	42	8.6	8.0	3.1	1.9-16.7
Moisture as Received (%)	44	11.1	10.2	3.91	2.8-18.2
Volatile matter (%)	43	39.7	39.6	2.39	35.4-44.4
Fixed carbon (%)	43	48.6	48.5	3.31	42.0-55.0
Ash (%)	44	11.8	11.7	1.97	7.4-16.5
Btu (per pound)	42	12518.	12511.	429.99	11562-13480
Carbon[a]	42	69.37	69.29	3.221	62.49-75.13
Hydrogen[a]	42	4.90	4.89	0.321	4.19-5.98
Nitrogen[a]	42	1.29	1.27	0.215	0.93-1.75
Oxygen[a]	42	9.09	8.92	1.85	5.75-14.36
High Temperature[a] Ash	43	11.86	11.69	1.979	7.34-16.46
Low Temperature[a] Ash	43	15.60	15.34	2.793	10.36-20.66
Organic Sulfur[a]	43	1.69	1.53	0.675	0.53-3.20
Pyritic Sulfur[a]	43	1.72	1.56	0.730	0.29-4.56
Sulfate[a]	42	0.09	0.04	0.17	0.01-0.90
Total Sulfur[a]	44	3.49	3.23	1.22	0.85-6.45
Sulfur by X-ray[a] Fluorescence	43	3.24	2.99	1.20	0.88-6.52

[a] Percent, Moisture Free Whole Coal Basis

3.1.1 Fugitive Emissions

3.1.1.1 Particulates

Fugitive emissions in the form of particulates will be emitted from the following sources:

- Coal storage piles
- Coal reclaiming and crushing
- Coal receiving
- Dryer stack gas
- Lime storage
- Ash from steam generation
- Recovered sulfur storage facility.

While little information is available on the composition of particulates, we can, as a first assumption, assume similarity to the parent coal, by-product, product, etc. Trace element composition in the fugitive emissions will be discussed under individual pollutants.

3.1.1.2 Coal Preparation

Coal dust is generated during the transfer of coal from shipping to receiving bins and during coal storage, conveying, stacking, reclaiming, and crushing operations. Dust is composed of coal particles, typically from 1 to 100 microns in size, with a composition similar to the parent coal. It is estimated that 21.8 Mg/day of particulates will be generated from coal receiving, storage, and crushing and 29 Mg/day of particulates will be emitted from dryer stack gas (1). By applying known removal efficiencies for particulates, estimates of emissions after control have been determined.

3.1.1.2.1 Dust from Coal Receiving

Before treatment the emissions amount to approximately 7.3 Mg/day (1). Assuming a gas stream flow of 1.9 m^3/sec with a loading of 44.6 grams/m^3 (34,689 ppm) and maximum removal efficiencies for the treatment equipment, emissions after treatment are estimated as follows:

TABLE 3-2. FUGITIVE DUST EMISSIONS FROM COAL RECEIVING AFTER TREATMENT

Treatment	Efficiency	Emissions after treatment	
cyclone + baghouse	99.9%	35 ppm	44.7 mg/m^3
high efficiency cyclone	99+	347 ppm	447 mg/m^3
wet-scrubber	98.5	520 ppm	669 mg/m^3

3.1.1.2.2 Dust from Reclaiming and Crushing

Coal dust generated from coal reclaiming and crushing has been estimated at 7.3 Mg/day without controls (1). Assuming four units, each handling 1.9 m^3/sec with a loading of 11.12 grams/m^3 (8,646 ppm), emissions after treatment are estimated as follows:

TABLE 3-3. FUGITIVE DUST EMISSIONS FROM COAL RECLAIMING AND CRUSHING FOLLOWING TREATMENT

Treatment	Efficiency of removal	Emissions after treatment (ppm)	Emissions after treatment (mg/m^3)
cyclone + baghouse	99.9%	8.6	11
high efficiency cyclone	99.0%	86.5	110
wet scrubber	98.5%	129.7	167

3.1.1.2.3 Dust from Coal Storage

The problem of controlling dust emissions from coal storage is a formidable one, insofar as the coal storage area is estimated to be 3.24 hectares. Polymer spraying is recommended to reduce dust emissions. It is also recommended that uncovered storage areas be minimized. Dust emissions following polymer spraying have not been estimated.

3.1.1.2.4 Dryer Stack Gas

Particulate emissions from dryer stack gas are estimated at 29 Mg/day without controls. This assumes that the flow dryer is equipped with a cyclone collector built within the unit.

Assuming 378 m^3/sec gas flow (1) at 60°C with a loading of 0.9 grams/m^3 (712 ppm) the estimated emissions with control technology are as follows:

TABLE 3-4. COAL DRYER STACK GAS EMISSIONS FOLLOWING TREATMENT

Treatment	Efficiency	Emissions after treatment	
cyclone	80% (<20μ)	142 ppm	183 mg/m^3
baghouse	99.9%	0.7 ppm	0.9 mg/m^3
wet scrubber	98.5%	10.7 ppm	13.5 mg/m^3

3.1.1.2.5 Comparison to Standards

Applicable standards for comparing emissions from coal preparation include New Mexico standards for commercial gasifiers, national air quality standards, and federal new source performance standards. Standards for coal preparation limit emission from thermal dryers to 70 mg/m^3. Cyclones would not be an acceptable control method for achieving coal preparation performance standards.

In comparing emissions to New Mexico gasification standards, it is evident that a cyclone plus baghouse would be required in coal receiving (Table 3-2) to reduce particulates to the allowable level of 69 mg/m^3, while in reclaiming and crushing all control methods are acceptable.

3.1.1.3 Lime Storage

No estimates are available on dust emissions from lime storage. These emissions are more likely to be a nuisance than a serious health hazard.

3.1.1.4 Fugitive Emissions from Sulfur Storage

Utilizing Illinois #6 coal specified in the Standards of Practice Manual (1), recovered sulfur is estimated to be 444 Mg/day. The recovered sulfur is expected to have the composition shown in Table 3-5 and emissions from sulfur storage can be expected to have a similar distribution of trace elements. Insofar as storage facilities have not been specified, it is not possible to estimate quantities of fugitive emissions from sulfur by-product storage. One possibility for preventing fugitive emissions would be to store by-product sulfur as a liquid. A more economically feasible method would be to store sulfur in a lined pond with a water blanket.

TABLE 3-5. TRACE ELEMENT ANALYSIS OF RECOVERED SULFUR (3)

Element	Concentration (mg/l)	Element	Concentration (mg/l)
As	2.0	Tb	0.1
Sb	0.1	Eu	0.0
Se	1.5	Sm	0.6
Hg	0.1	Ce	2.0
Br	3.0	La	1.8
Ni	28.0	Sr	45.0
Co	110.0	Ba	39.0
Cr	2.0	Th	0.2
Fe	1,000.0	Hf	0.2
Na	3,120.0	Ta	0.2
Rb	9.0	Ga	1.5
Cs	0.2	Zr	61.0
K	179.0	Cu	1.0
Sc	0.02		

3.1.1.5 Particulates from Steam Generation

The steam generation module advocated in the Standards of Practice Manual (1) utilizes coal-fired boilers. A total of 929 Mg/day of coal are required to generate the needed steam. Particulates in the stack gas from steam generation have been estimated at 36.6 Mg/day. Particulates in the stack gas are recovered as fly ash and can be a potential source of emissions if not handled properly. This will be considered as a solid waste problem. In order to meet Illinois emission standards, particulates from coal-fired boilers must be removed with an efficiency of 98.65 percent, reducing emissions to 0.49 Mg/day. Elbair scrubbers and venturi scrubbers are capable of removal up to 99 percent of the particulates in fly ash. Medium-energy venturi scrubbers will remove almost 100 percent of particulates <50 microns, 99 percent of particulates <5 microns, and 97 percent of particulates <1 micron.

3.1.1.6 Hydrocarbons

Fugitive hydrocarbon emissions will be limited largely to leaks in pump seals, joints, flanges, compressors, and to handling and venting operations. There are no estimates on the quantities of hydrocarbons lost in fugitive emissions, but the source is largely controllable. In some cases simply tightening pipe fittings and flanges will greatly reduce hydrocarbon emissions. Several hydrocarbon emission controls are discussed in the Standards of Practice Manual (1).

Possible sources of hydrocarbon emissions include:

- Pulverizing, drying, and slurry mixing steps in coal preparation
- The hydrogenation module
- Several areas of the phase-separation

- Product and solvent fractionation
- Product and by-product storage.

Small quantities of gas will continuously be disposed of in an elevated combustion flare system. While the flare loading cannot be estimated, a comparable-size refinery flares about 13.6 Mg/day. Examination of combustion products from elevated flares shows the following relationship (4):

CO_2: hydrocarbons	2100:1
CO_2: CO	243:1

Other air contaminants depend upon the composition of the gas burned. H_2S will be emitted as SO_2. Nitrogen oxides will be emitted as a combustion contaminant.

The third area in which hydrocarbon emissions may be a problem is in product and by-product storage. In an environmental overview of a commercial SRC-II facility (5) product storage specifications have been made which should greatly reduce hydrocarbon emissions. The specifications for each fraction are given below.

LPG will be stored and shipped in heavy walled, pressurized tanks and consequently any hydrocarbon emissions would be fugitive losses from valves, fittings, and seals which must be regularly checked.

Naphtha should be stored in a floating roof storage tank. The floating roof will eliminate working losses which are the major source of hydrocarbon emissions. Floating roof standing storage emissions will be variable depending upon tank design, age, etc. Based on a simplified estimation

(6), we can expect between 5.44 g/day and 13.2 g/day for the 525 Mg/day of naphtha produced. We would expect 772 to 1,907 g/day of hydrocarbon emissions from naphtha storage.

Fuel oil will be stored and shipped in atmospheric pressure tanks. Hydrocarbon emissions from fixed roof storage have been estimated at 4.56 g/m^3/day for breathing emissions and 120 g/m^3 for filling emissions. For fuel oil production rates of 2,615 Mg/day, hydrocarbon emissions will be approximately 0.32 Mg/day.

Product SRC-I is produced at a rate of 5,527 Mg/day and storage of this product will result in losses of roughly 0.66 Mg/day. Total hydrocarbon emissions are therefore a minimum of 0.98 Mg/day. The sum of the hydrocarbon emissions is about 1.3 Mg/day.

With these significant hydrocarbon emissions, the storage tank area should have a vapor recovery system to return vapors to the gas purification module. Loading facilities will also need a vapor recovery system to return vapor from the transport tanks to the storage tanks as the liquid is loaded.

The Stretford tail gas is another source of hydrocarbon emissions, the quantity of hydrocarbons being dependent upon the treatment alternative chosen. Hydrocarbon emissions following direct-flame incineration are 79.0 ppm and emissions following carbon absorption/incineration are 278 ppm. Illinois standards for petrochemical plants require that emissions be less than 100 ppm; consequently, carbon absorption/incineration would be inadequate.

A final source of hydrocarbon emissions is the result of the adsorption of organics to particulates which are emitted to the atmosphere. Particle size is the physical property with the greatest influence on the behavior of polynuclear aromatic hydrocarbons. Polycyclic organics are largely associated with particles less than 5 microns in diameter. The smaller the particles, of course, the more likely they will be to escape pollution control devices. It is not possible to quantify the total hydrocarbons emitted in particulate streams.

3.1.1.7 Cooling Tower Emissions

There are currently no emission standards for cooling towers. In view of the large quantities of evaporation and drift (22,448 Mg/day) (1) these losses warrant environmental concern.

Tower evaporative losses, having undergone distillation, should be quite free of dissolved solids. Thus, impact will be limited to the effect of excess water vapor in the air near the plant.

Cooling tower drift results from water droplets mechanically generated in the tower. The composition can be expected to be similar to the tower circulating water. This could result in contamination from dissolved minerals and corrosion inhibitors. The actual composition of drift depends upon the number of circulations as a multiple of the river salinity. This is somewhat complicated by the fact that a blowdown from steam generation will be used in cooling tower make-up. In addition, an unidentified quantity of the corrosion inhibitors and antifouling agents are lost in drift.

3.1.1.8 Air Pollution Associated with Regeneration of Activated Carbon and Catalysts

There is no indication to date that catalysts or activated carbon would be regenerated on site.

It is conceptualized that spent carbon be removed in specially designed hoppers and hauled off-site where it can be regenerated in a controlled atmosphere. Reactivation would take place in a multiple hearth furnace at about 980°C.

Catalyst used in the shift reaction in hydrogen generation has been estimated at about 135 m^3 (7). As gas passes over the catalyst, some trace elements are adsorbed or absorbed on the catalyst. Sulfur compounds and heavy hydrocarbons may likewise be sorbed. The estimated life of this catalyst is one year.

Cobalt molybdate catalyst with an estimated three-year life span will probably be used in the hydrotreating module, and would be contaminated with nitrogen and sulfur compounds and trace elements.

A wide variety of contaminants may be produced in catalyst regeneration. They include catalyst dust, oil mists, hydrocarbons, sulfur oxides, chlorides, cyanides, nitrogen oxides, carbon monoxide, and particulates.

Insofar as the catalysts have a fairly long lifetime, it is suggested that they be regenerated at off-site facilities with the proper air pollution controls.

3.1.2 Individual Pollutants From the Modules

3.1.2.1 Coal Drying

Emissions from thermal dryers include the combustion products, NO_x and SO_2. However, these concentrations are very small and have not been indicated in the stack gas composition from the thermal drying operation (1). Both NO_x and SO_2 from well-controlled thermal dryers processing low sulfur coal have been found to be below the performance standards of new coal-fired power plants (7). SO_x concentrations of 0 to 11.2 ppm have been reported for coal with a 2 percent sulfur content. Roughly twice this amount may be expected from Illinois No. 6 coal (approximately 4 percent sulfur).

3.1.2.2 Sulfur Recovery

Acid gas from the gas purification module (705 Mg/day) and gas from hydrogen production (5,912 Mg/day) are routed to the Stretford unit where H_2S (472 Mg/day) is recovered as elemental sulfur. The process is greater than 99.5 percent efficient in sulfur recovery, yielding 2.35 Mg/day of hydrogen sulfide.

Treatment of the tail gas may be by direct-flame incineration or by carbon absorption with incineration. The stream compositions after treatment are shown in Table 3-6.

In either treatment method hydrogen sulfide emission standards for commercial gasifiers (State of New Mexico) are met. This standard is 10 ppm. The sulfur emission standard in New Mexico for commercial gasifiers is 0.014 kg/kcal (heat input of feed). At a coal heating value of 2.99×10^7 joules/kg, the allowable sulfur discharge is

TABLE 3-6. EMISSIONS AFTER TREATMENT OF STRETFORD TAIL GAS

Component	Direct flame incineration (98%)	Carbon adsorption incineration (99%)
H_2S	0.2 ppm	10 ppm
SO_2	17.7 ppm	
Hydrocarbons	79.0 ppm	278 ppm
NO_x (as NO)	96.6 ppm	0.5 ppm
CO	2.5 ppm	12.7 ppm
CO_2	43.6%	43%
NH_3	2.0 ppm	111 ppm

1.89 Mg/day. This standard could be met without tail gas treatment. Industrial emission standards in Arizona require greater than 90 percent sulfur removal.

3.1.2.3 Coal-Fired Boilers

Coal utilized in the SRC process in this study has a sulfur content of 3.5 percent. Sulfur will be emitted as sulfur dioxide in coal-fired boilers. Assuming 96 percent conversion of sulfur to sulfur dioxide and assuming that 929 Mg of coal are required for steam generation, roughly 65 Mg/day of sulfur dioxide will be emitted in the flue gas (1).

A component analysis of the boiler flue gas is shown in Table 3-7.

TABLE 3-7. COMPONENT ANALYSIS OF BOILER FLUE GAS (1)

Constituent	Quantity (Mg/day)	G-moles/day	Concentration
N_2	8,512	3.0×10^8	77.0%
CO_2	2,050	4.7×10^7	12.1%
H_2O	410	2.3×10^7	5.9%
O_2	597	1.9×10^7	4.9%
NO_x (as NO)	8.4	2.8×10^5	0.07%
SO_2	65	1.0×10^6	0.25%
HC (ethane)	0.14	4.7×10^3	11.3 ppm
Particulates	36.6	-------	40 grams/m^3

The total flow rate of flue gas is 107 m^3/sec (standard conditions at 0°C and atmospheric pressure) and the SO_2 concentration is 2,465 ppm. Removal of SO_2 by various methods is as follows:

TABLE 3-8. SULFUR DIOXIDE CONCENTRATIONS IN BOILER FLUE GAS FOLLOWING VARIOUS TREATMENT METHODS

Treatment	Removal efficiency	Sulfur dioxide emissions after treatment mg/day	Sulfur dioxide concentration g/m^3
Lime slurry scrubber	90%+	6.5	7.1
Soda limestone double alkali	90%+	6.5	7.1
Limestone scrubber	70%+	19.5	21.0

Allowable daily sulfur dioxide levels from coal-fired boilers in the state of Illinois are 14.1 Mg/day, suggesting that use of a limestone scrubber may be inadequate to meet standards, while the other two treatment systems emit sulfur dioxide significantly below the standards.

3.1.2.4 NO_x

The reported sources of NO_x emissions within the SRC plant include:

Steam generation	8.4 Mg/day
Stretford effluent gas as NO	0.005 Mg/day

The Illinois emission standards for coal-fired boilers require that NO_x emissions do not exceed 0.3 g/M joules of feed coal. Total allowable daily emissions, assuming this standard, are 8.3 Mg/day. Consequently, only a 2 percent reduction in NO_x emissions is required to meet standards. This is best accomplished by combustion modifications; however, flue gas treatment could also be used. Reducing excess air rates may not be as effective or damage-proof as other modification techniques. In coal firing, serious imbalances in fuel/air distribution may result from lower excess air. One very effective method would be the two-stage combustion zone. In this method 90 to 100 percent of the theoretical combustion air is injected into the burner, with the remainder being introduced a few meters downstream of the burner. By supplying the substoichiometric quantities of primary air to burners, 40 to 50 percent NO_x reductions have been observed. Another effective method of reducing NO_x is by recirculation of coal flue gas, which lowers peak flame temperature by diluting the primary flame zone with the recirculated gas. Most existing units are limited to 20 percent recirculation.

Another source of NO_x emissions may be the thermal dryer in coal preparation, although these emissions are reportedly below performance standards for coal-fired power plants, if the dryer is well controlled (8).

3.1.2.5 CO and CO_2 Emissions

CO and CO_2 are discharged from several point sources within SRC. The following point sources are noteworthy:

TABLE 3-9. CARBON MONOXIDE AND CARBON DIOXIDE EMISSIONS FROM SEVERAL POINT SOURCES

Source	CO_2 Mg/day	CO (ppm)
Stack gas from coal drying	488	---
Stretford process offgas		
a. Direct flame incineration	6,033	2.5 ppm
or		
b. Carbon absorption & incineration	6,030	12.7 ppm
Gasifier CO_2 scrubber	685	---
Steam & power generation	2,322	45.2 ppm
Process & auxiliary related flue gases	3,777	---
Flare waste gases	Not quantified	Not quantified

There are no standards regarding the emissions of more than 13,000 Mg/day of CO_2, nor are any anticipated. Quantities of 45.2 ppm CO are far below the Illinois coal-fired boiler emission standards of 125 ppm. Similarly the low quantities of CO emitted from the Stretford process (1.6 ppm) are not significant.

3.1.2.6 Trace Element Composition of Particulates From Coal Preparation

The trace element distribution in particulates is somewhat a function of particle size. This factor complicates our efforts to estimate the trace element makeup in a stream containing particulates. Table 3-10 is a first approximation of the trace element makeup in treated dust streams from the coal preparation module, including coal receiving, crushing, and drying. The minimum value listed in this table refers to the concentration of elements in the dust stream emanating from the most effective dust control device (a cyclone with baghouse), and the maximum refers to the dust emitted from the least effective acceptable control device (wet scrubber). This approximation assumed that trace elements are evenly distributed in dust particles independent of particle size. In an analysis of the trace element composition in different particle sizes of coal dust from a Pittsburgh seam coal, 27 trace elements were found to be evenly distributed independent of particle size, while 11 trace elements were distributed in concentrations that varied with particle size (9).

3.1.2.7 Particulates in Stack Gas From Steam Generation

Enrichment volatilization behavior of trace elements is determined by the physiochemical properties of the elements and their chemical compounds in coal and combustion products. A group of trace elements including Cu, Zn, As, Mo, Pb, Po, and Se have a tendency to vaporize in the furnace and then to condense or absorb onto the fly ash. Smaller particles will have larger specific surface areas and thus will have a greater concentration of these elements. These

TABLE 3-10. APPROXIMATE TRACE ELEMENT COMPOSITION FROM CONTROLLED EMISSIONS IN COAL PREPARATION

Name	Symbol	Minimum $\mu g/m^3$	Maximum $\mu g/m^3$	Minimum g/day	Maximum g/day	Minimum Degree of Hazard (Health)*	Maximum Degree of Hazard (Health)*
Aluminum	Al	760.	11,500.	590.	8,910.	0.15	2.21
Antimony	Sb	0.06	0.83	0.04	0.64	0.00	0.00
Arsenic	As	0.33	5.0	0.26	3.9	0.17	2.50
Barium	Ba	6.28	94.	4.84	73.	0.01	0.19
Beryllium	Be	0.08	1.3	0.07	0.98	0.04	0.65
Boron	B	7.64	115.	5.9	89.	0.00	0.04
Cadmium	Cd	0.23	3.4	0.17	2.61	0.02	0.34
Calcium	Ca	435.	6,500.	335.	5,100.	----	----
Cerium	Ce	0.74	11.	0.57	8.6	----	----
Cesium	Cs	0.07	1.0	0.05	0.78	----	----
Chlorine	Cl	91.	1,350.	70.	1,056.	----	----
Chromium	Cr	1.13	17.	0.87	13.	1.13	17.0
Cobalt	Co	0.37	5.6	0.29	4.4	0.01	0.11
Copper	Cu	0.74	11.	0.57	8.6	0.00	0.06
Dysprosium	Dy	0.06	0.85	0.04	0.65	----	----
Europium	Eu	0.014	0.21	0.01	0.16	----	----
Fluorine	F	3.56	53.	2.75	42.	----	----
Gallium	Ga	0.18	2.6	0.14	2.0	0.00	0.00
Germanium	Ge	0.32	4.8	0.24	3.7	0.00	0.01

*Degree of hazard (health) is obtained from the ratio: $\frac{\text{concentration in air from coal dust streams}}{\text{MATE value (health) from MEGs}}$

(continued)

TABLE 3-10. (continued)

Name	Symbol	Minimum $\mu g/m^3$	Maximum $\mu g/m^3$	Minimum g/day	Maximum g/day	Minimum Degree of Hazard (Health)*	Maximum Degree of Hazard (Health)*
Hafnium	Hf	0.029	0.044	0.023	0.34	----	----
Indium	In	0.01	0.12	0.01	0.09	----	----
Iodine	I	0.11	1.6	0.08	1.3	----	----
Iron	Fe	1,100.	16,000.	810.	12,000.	----	----
Lanthanum	La	0.40	5.9	0.31	4.6	----	----
Lead	Pb	1.5	23.	1.2	18.	0.01	0.15
Lutetium	Lu	0.0045	0.068	0.0035	0.053	----	----
Magnesium	Mg	29.	430.	22.	337.	0.00	0.07
Manganese	Mn	3.0	45.	2.3	35.	0.00	0.01
Mercury	Hg	0.010	0.15	0.0078	0.12	0.00	0.00
Molybdenum	Mo	0.52	7.8	0.40	6.1	0.00	0.00
Nickel	Ni	1.2	19.	0.96	15.	0.08	1.27
Phosphorus	P	2.5	38.0	2.0	30.	0.03	0.38
Potassium	K	96.	1,400.	74.	1,100.	0.05	0.70
Rubidium	Rb	0.91	14.	0.70	11.	----	----
Samarium	Sm	0.068	1.0	0.052	0.79	----	----
Scandium	Sc	0.15	2.2	0.11	1.7	0.00	0.00
Selenium	Se	0.12	1.9	0.10	1.5	0.00	0.01
Silicon	Si	1,500.	23,000.	1,200.	18,000.	----	----
Silver	Ag	0.0016	0.025	0.0013	0.020	0.00	0.00

*Degree of hazard (health) is obtained from the ratio: $\frac{\text{concentration in air from coal dust streams}}{\text{MATE value (health) from MEGs}}$

(continued)

TABLE 3-10. (continued)

Name	Symbol	Minimum $\mu g/m^3$	Maximum $\mu g/m^3$	Minimum g/day	Maximum g/day	Minimum Degree of Hazard (Health)*	Maximum Degree of Hazard (Health)*
Sodium	Na	37.	560.	29.	436.	----	----
Strontium	Sr	2.0	31.	1.6	24.	0.00	0.01
Tantalum	Ta	0.0091	0.14	0.0070	0.11	----	----
Thallium	Tl	0.038	0.57	0.029	0.44	0.00	0.01
Thorium	Th	0.12	1.0	0.096	1.45	----	----
Tin	Sn	0.27	4.0	0.20	3.1	0.00	0.04
Titanium	Ti	40.	600.	31.	460.	0.00	0.10
Tungsten	W	0.040	0.59	0.031	0.46	0.00	0.00
Uranium	U	0.091	1.4	0.070	1.05	0.01	0.16
Vanadium	V	1.87	28.	1.4	22.1	0.00	0.05
Ytterbium	Yb	0.031	0.46	0.024	0.35	----	----
Zinc	Zn	24.	350.	18.	280.	0.01	0.09
Zirconium	Zr	2.9	44.	2.3	34.	----	----

*Degree of hazard (health) is obtained from the ratio: $\frac{\text{concentration in air from coal dust streams}}{\text{MATE value (health) from MEG's}}$

trace elements are most likely to be present in the elemental form or as oxides. Table 3-11 shows estimated concentration of several trace elements in stack gas particulates escaping from control devices.

TABLE 3-11. ESTIMATED CONCENTRATIONS OF SELECTED TRACE ELEMENTS IN PARTICULATES ESCAPING CONTROL DEVICES IN TREATED STACK GAS (10)

Element	Concentration (μg/g)	Amount (kg/24 hr)
Cu	429	1.85
Zr	676	2.92
Rb	309	1.33
Sr	749	3.24
Zn	212,152	920.0
Mo	553	2.39
Se	69	0.30

3.1.2.8 Organics Emitted with Particulate Matter

Unquantified amounts of polynuclear aromatic hydrocarbons (PAH) are expected to be emitted with particulates which escape air pollution control equipment.

3.2 Water Effluents

Various studies on the pollution potential of coal conversion processes have cited effluent water quality as a particular area of concern since process waters from these plants contain cyanides, phenols, ammonia, sulfides, and dissolved solids. This would be of minimal concern in the commercial SRC facility if the water could be reused as has been suggested in the Standards of Practice Manual (1).

Presently, the Fort Lewis SRC pilot plant is demonstrating the applicability of various treatment systems to treat the wastewater for discharge. However, the wastewater is diluted with cooling water and therefore treatment results are not strictly applicable to a commercial facility.

Organic pollutants generated in the proposed SRC plant will largely be formed within the process itself, with little contribution from hydrogen generation or other auxiliary facilities. The proposed Koppers-Totzek gasifier operates in the entrained flow mode and as such, the average bed temperatures are too high for phenols, tars, and oil to be present in the discharged gas stream. Furthermore, ammonia and cyanides are formed in amounts well under one volume percent.

The data used to evaluate pollutant levels expected to be discharged from a once-through wastewater treatment system are based upon Fort Lewis pilot plant data (11,12,13), the AWARE report on the treatability of H-Coal wastewater (14), and analyses of Synthane gasifier process condensate (12). The assumption that Synthane process condensate is similar to SRC foul water is only a first approximation. A comparison of the condensate from the two processes shows similarity in COD and phenol levels (12).

3.2.1 Complex Effluents

For the purpose of the ensuing discussion, complex effluents are defined as including the following pollutants:

- Oil and grease
- Suspended solids
- Dissolved solids

- COD, TOC, BOD
- pH.

As mentioned elsewhere, the process wastewater contributes almost all of the organic pollutants generated in the SRC facility. The foul water is the most polluted water in the overall process. The composition of this stream is estimated in Table 3-12.

TABLE 3-12. CHARACTERIZATION OF FOUL PROCESS WATER (12)

Component	Effluent range (g/1)	Source of data
Total organic carbon	6.6-7.3	Analysis of foul process condensate SRC; Kentucky - Bituminous Coal (12)
Total carbon	8.2-9.0	
BOD (5 days)	32.5	
COD	25.0-43.6	
Oil and grease	0.03-0.60	Foul process condensate H-Coal PDU (14)
Dissolved solids	2.7-5.3	
Suspended solids	0.002-0.020	

Foul water represents some 80 percent of process-related wastewaters which consist of the following items (1):

- Foul process condensate - about 3130 m^3/day
- Decanter wastewater-hydrotreating - about 790 m^3/day
- Wastewater from gas purification - about 6 m^3/day
- Wastewater from cryogenic separation - about 33 m^3/day.

The sum of these items is about 3,960 m^3/day.

Nonprocess-related water which will be treated in wastewater treatment units consists of:

Raw water	32,057 m^3/day
Cooling tower blowdown	693 m^3/day
Oily water runoff	Unquantified

It has been conceptualized that boiler blowdown will be sent to the cooling tower. Cooling tower blowdown is actually a purge stream, and it will be treated separately by ion exchange or reverse osmosis and subsequently discharged to the river (1). The cost and feasibility of this method require further examination.

Gasifier effluent and coal pile runoff will be treated in settling units only.

3.2.1.1 COD, BOD, and TOC

The treatability and final effluent levels for nonchemical water parameters can only be accurately evaluated by actual plant data. Residual concentrations can only be roughly estimated.

Phenol concentration in the foul water process condensate was reported to be 10,000 mg/l in the Standards of Practice Manual (1), which represents between 47 and 64 percent of the total COD (10). Phenol recovery should reduce the COD concentrations to 13,000 to 26,500 mg/l. The ability of activated sludge to reduce COD in the foul process condensate was investigated by AWARE Associates for the H-Coal process (14). As expected, removal efficiency is dependent upon loading rates to the activated sludge units. Operational data indicate that a removal rate of 0.22 g BOD/g MLVSS-day be used for design. Under the optimum conditions of this investigation, 99 and 93 percent of the influent BOD and COD, respectively, could be removed. Influent COD ranged from 2700 to 4200 mg/l and influent BOD ranged from 1700 to 2700 mg/l. The refractory BOD and COD were 5 mg/l and 150 mg/l, respectively. Foul process condensate would have to be diluted significantly to obtain these desired organic loading rates. An alternative would be to use high-purity oxygen-activated sludge (HPOAS). Experience with HPOAS systems in the coking industries suggests that this may be an effective treatment method. Effluent soluble BOD_5 of 45 mg/l can be successfully achieved for the following loading conditions (12):

- BOD_5 - 18,000 mg/l
- COD - 28,000 mg/l
- COD/BOD_5 - 1.56

The effectiveness of the method for treatment of liquefaction wastewaters, in which readily degraded phenols make up less of the total COD, needs to be tested. Phenols have been estimated to make up 68 percent of the COD of coking effluents.

The use of activated carbon for tertiary treatment has been shown to effectively reduce COD in treatment of the pilot plant wastewater (14); however, activated carbon absorption of industrial wastes must be carefully evaluated. Breakthrough geometry and adsorption kinetics of multicomponent wastewaters are difficult to define. Certain organics which would be encountered are not amenable to activated carbon treatment. A third problem area with activated carbon is that regeneration of carbon capacity cannot be accurately estimated. Carbon adsorption pilot plant results from petrochemical and refinery wastewaters show that for a COD of 100 to 150 mg/l, the percent removal ranges from 59 to 67 percent (15). Assuming that 150 mg/l COD is the refractory COD from biological treatment, as observed for the H-coal foul process condensate, effluent CODs may be as low as 49.5 to 61.5 ppm.

If the refractory BOD is closer to 45 ppm, we may expect a COD of approximately 340 mg/l from biological treatment. This treatment assumes that the relationship:

$$BOD_T = 0.66\ COD_T - 180$$

determined for the H-coal sour water (14) holds true for SRC sour water as well. It cannot be accurately determined if effluent BOD concentrations would continuously meet Illinois requirements of 20 ppm.

3.2.1.2 Oil and Grease

Oil and grease will be removed in wastewater treatment largely by dissolved air flotation, possibly accompanied by an API separator. The main source of oil and grease is the foul process condensate and oily water runoff. The contribution by the latter is unknown and variable.

Bench-scale application of dissolved air flotation to the H-coal foul process condensate showed oil and grease removal efficiency of 70 percent without use of emulsion-breaking chemicals. Table 3-13 shows the ranges of oil removal efficiencies that have been reported for dissolved air flotation (DAF) (16):

TABLE 3-13. EFFICIENCIES OF OIL REMOVAL FROM WASTEWATER BY DISSOLVED AIR FLOTATION

	Oil removed - free oil	Oil emulsions
Air flotation (no chemical)	70-95%	10-40%
Air flotation & emulsion-breaking chemicals	75-95%	50-90%

There are few states with discharge criteria for oil and grease. Colorado has an effluent discharge standard of 10 mg/l. Use of DAF alone would probably be insufficient to meet these standards. Addition of emulsion-breaking chemicals may increase efficiency up to 90 percent. During stable operations of activated sludge units treating H-Coal sour water, oil and grease concentrations were reduced by 75 to 90 percent for influent concentrations ranging from 20 to 75 mg/l (14). Therefore, use of activated sludge and DAF with emulsion-breaking chemicals should reduce oil and grease to acceptable levels.

3.2.1.3 Dissolved and Suspended Solids

There are several waste streams which require treatment for dissolved and suspended solids, the degree of treatment depending largely upon the end use of the water.

3.2.1.3.1 Coal Pile Runoff

The concentrations of dissolved and suspended solids from coal pile runoff will be highly variable. Table 3-14 shows a range of 247 to 44,050 mg/l for total dissolved solids and 22 to 3302 mg/l for suspended solids in coal due

TABLE 3-14. CHEMICAL WASTES CHARACTERISTICS OF COAL PILE DRAINAGE (mg/1) (17)

Characteristic	n*	Arithmetic mean	Geometric mean	Standard deviation	Standard error of the mean	Range
Alkalinity	8	20.0	0.0	28.1	9.9	0-36.41
BOD	4	3.3	0.0	4.7	2.4	0-10
COD	5	820	615	434	194	85-1,099
Total solids	6	11,200	5,070	17,000	6,900	1,330-45,000
Total dissolved solids	7	12,600	3,600	17,000	6,500	247-44,050
Total suspended solids	7	830	340	1,140	430	22-3,302
Ammonia	5	0.69	0.00	0.82	0.37	0-1.77
Nitrate	5	1.31	0.93	0.94	0.42	0.3-2.25
Phosphorus	2	0.72	0.53	0.69	0.48	0.23-1.2
Turbidity	5	200	32	270	120	2.77-505
Acidity	5	9,900	216	13,700	6,000	8.68-27,810
Total hardness	4	800	430	840	420	130-1,850
Sulfate	8	6,900	2,200	8,800	3,100	133-21,920
Chloride	4	130	19	240	118	3.6-481
Aluminum	2	1,000	990	260	190	825-1,200
Chromium	6	2.7	0.0	6.4	2.6	0.0-15.7
Copper	4	2.1	2.0	0.9	0.4	1.6-3.4
Iron	9	10,900	4	30,800	10,300	0.06-93,000
Magnesium	2	130	124	60	42	89-174
Zinc	7	5.9	1.0	8.9	3.3	0.006-23
Sodium	3	890	630	630	370	160-1,260
pH	11	4.4	4.0	2.1	0.6	2.8-7.8

*n = number of samples taken for a particular analysis.

to runoff from several sources (17). The acidic nature of this runoff can cause the dissolution of inorganic salts which are present in the coal. The high alkalinity of coal from the Illinois region is likely to neutralize much of the sulfuric acid, thus decreasing the solubility of the salts. Consequently, we can expect Illinois #6 coal to release pollutants at the lower end of the concentration ranges. However, unless an impervious lining is placed in the ponds and preventive measures are taken to avoid overflow, serious ground pollution problems could result. Insofar as end use of the coal pile runoff is for coal washing, water quality is not significant except from the standpoint of overflow from the settling ponds. Settling ponds should be designed to contain maximum runoff.

3.2.1.3.2 Ash Pond Effluent

Bottom and fly ash from steam generation may be routed to settling ponds or, alternatively, collected in trucks and hauled off-site. The characteristics of ash pond effluent for coal-fired power plants which use Illinois or western Kentucky coals are shown in Table 3-15 (17). In both plants suspended solids concentrations are much lower than concentrations of dissolved solids. Nevertheless, suspended solids levels are too high to meet BPCTCA (best practical control technology currently available) or BATEA (best available technology economically achievable) levels of 30 mg/l for bottom ash or fly ash transport water. The high concentrations of suspended solids in some ash ponds are probably caused by low-density, hollow-sphere ashes (cenospheres) which cannot be removed in the pond by natural settling. Some means of removing the cenospheres would be required to meet effluent guidelines for suspended solids if the water was discharged. It is more likely that the water will be reused in the process, although its use is restricted by

TABLE 3-15. CHARACTERISTICS OF ASH POND EFFLUENT FROM COAL-FIRED POWER PLANTS RUN ON KENTUCKY BITUMINOUS OR ILLINOIS COAL (17)

	Plant 1[a]				Plant 2[b]			
Parameter	Min (mg/1)	Ave (mg/1)	Max (mg/1)	Degree of Hazard Health (Avg)	Min (mg/1)	Ave (mg/1)	Max (mg/1)	Degree of Hazard Health (Avg)
Total alk. ($CaCO_3$)	33	113	173	-	58	96	187	-
pH	10.5	11.2	11.4	-	9.4	10.8	11.4	-
Dissolved solids	12	452	1410	-	23	232	416	-
Suspended solids	1	39	182	-	2	14	59	-
Aluminum	0.8	2.0	3.1	0.025	0.5	1.7	2.4	0.021
Ammonia	0.03	0.15	0.38	-	0.02	0.06	0.16	-
Arsenic	<0.005	<0.005	0.005	0.020	<0.005	0.012	0.025	0.048
Barium	<0.1	0.2	0.5	0.040	<0.1	0.2	0.3	0.040
Beryllium	<0.01	<0.01	<0.01	0.33	<0.01	<0.01	<0.01	0.33
Cadmium	0.001	0.001	0.002	0.02	0.001	0.001	0.001	0.02
Calcium	74	115	160	0.479	52	87	130	0.363
Chloride	4	5	6	-	7	12	19	-
Chromium	0.012	0.043	0.072	0.172	0.014	0.021	0.026	0.084
Copper	0.01	0.02	0.04	0.04	<0.01	0.05	0.10	0.10
Cyanide	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	-
Iron	0.05	0.23	1.10	0.153	0.11	0.24	0.34	0.160
Lead	<0.01	0.01	0.04	0.04	<0.01	0.025	0.04	0.100
Magnesium	0.2	2.0	7.2	0.022	0.4	1.0	3.0	0.011
Manganese	<0.01	0.01	0.04	0.040	<0.001	0.001	0.02	0.040
Mercury	<0.0002	0.038	0.300	3.8	<0.0002	0.0004	0.0008	0.040
Nickel	<0.05	<0.05	<0.05	0.217	0.05	0.07	0.22	0.304
Selenium	0.009	0.016	0.028	0.320	<0.002	0.011	0.016	0.220
Silver	<0.001	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.04
Sulfate	14	156	240	-	55	87	110	-
Zinc	<0.01	0.04	0.06	0.001	<0.01	0.05	0.11	0.002

[a] Plant 1 - utilized W. Kentucky and/or S. Illinois coal
method of firing - opposed
ash content of coal - 16.3%
% fly ash of total ash - 80%

[b] Plant 2 - utilized W. Kentucky and/or S. Illinois coal
method of firing - circular
ash content of coal - 15.6%
% fly ash of total ash - 75%

high levels of dissolved solids. Complete reuse would require dissolved solids removal by reverse osmosis, electrodialysis, or ion exchange.

3.2.1.3.3 Dissolved and Suspended Solids in Foul Process Water

As was mentioned earlier, dissolved and suspended solids levels in the foul process condensate are 2690 to 5390 mg/l and 2 to 20 mg/l, respectively. Decanter wastewater from hydrotreating is reported to contain certain trace elements, but levels of suspended and dissolved solids have not been reported.

The very low level of suspended solids (2 to 20 ppm) from the process water does not warrant treatment. Dissolved solids, on the other hand, are very high (2690 to 5300 ppm) and removal efficiencies in wastewater treatment depend upon the particular dissolved species. Dissolved solids, as such, are not particularly harmful assuming that the individual pollutant limits have been specified. The effluent dissolved solids levels are not known at this time.

3.2.1.3.4 Solids in Cooling Tower Blowdown

The blowdown from the recirculating cooling system has the same chemical composition as does the recirculating cooling water. Soluble constituents in make-up water, however, are concentrated as high as 1500 mg/l to 10,000 mg/l before being removed in the blowdown stream. The raw water supply in White County, Illinois, is characterized in Chapter 4 of this report. A sidestream filter should remove most suspended solids generated in the cooling system. It has been conceptualized that the blowdown be treated separately, using reverse osmosis or ion exchange to remove dissolved solids to acceptable levels; these processes are highly effective in removing dissolved solids. Thus, it may be necessary to only treat a portion of the stream and to recombine the treated and untreated streams before discharge. The feasibility and cost effectiveness of these treatment methods remain to be demonstrated.

3.2.1.3.5 Suspended Solids from the Gasifier

The water from the clarifier in the Koppers-Totzek gasifier will be recirculated as quench water unless the quality is too poor. An analysis of water out of the clarifier shows suspended solids levels of 50 mg/l. With such levels, overflow of the clarifier should not present any serious suspended solids problems.

3.2.2 Individual Pollutants from the Modules

3.2.2.1 Phenols

Foul process condensate and cryogenic separator wastewater are the only wastewater streams routed to phenol recovery. The phenol content is estimated to range from 5,000 to 12,000 ppm (12) and was reported to be 10,000 mg/l in the Standards of Practice Manual (1). The value of total phenols reported in the Standards of Practice Manual (1) lies at the high end of the range at 10,860 mg/l for foul process condensate and at 11,800 mg/l for cryogenic separator wastewater. Phenol recovery by solvent extraction can be 99.9 percent effective in phenol recovery; 99 percent recovery will be assumed.

The relative distribution of individual phenolic compounds in the SRC wastewater is not known. As a first approximation, the distribution found in Synthane gasification process operating with Illinois #6 coal is assumed. These data are shown in Table 3-16 (13).

The concentration of phenols entering biological treatment was determined by assuming that COD of the decanter wastewater is essentially zero, that this stream is a diluent and that the phenol concentration of cryogenic separation wastewater is 11,800 mg/l (1). Decanter wastewater will have some COD, but it will be low compared to foul water. No estimates can be made regarding oily water runoff at this time and it has not been considered as a diluent or as a significant contribution of phenol.

Calculated values shown in Table 3-15 indicate levels of biological oxidation somewhat similar to those observed in the Fort Lewis Pilot Plant, where influent concentrations to biological treatment of 10 to 1000 ppm phenol are reduced to 0.1 to 3.0 ppm. The effluent following carbon adsorption and sand filtration ranges from 0.0-0.6 ppm phenol in the pilot plant, indicating that a tertiary polishing step could further reduce even very low phenol concentrations (18). Estimations of achievable levels of phenol reduction in a commercial system cannot be accurately assessed.

Effluent guidelines for phenols have been established for the by-product coking industry (0.0006 kg/kg product - daily maximum) and for the petroleum refining industry, subcategory topping (0.088 kg/km^3 of feedstock - daily maximum).

3.2.2.2 Polynuclear Aromatic Hydrocarbons

Table 3-16 shows concentration levels of polynuclear aromatic hydrocarbons (PAH) observed in raw process water from the SRC process. The plant was operating in the SRC-I

TABLE 3-16. DISTRIBUTION OF PHENOLIC COMPOUNDS FOLLOWING PHENOL RECOVERY AND BIOLOGICAL TREATMENT (13)

Phenolic compound	Relative distribution in foul process water*	Concentration after 99% recovery (mg/l)	Concentration to biological** treatment (mg/l)	% Biol. oxidation assumed	Bio-unit effluent (mg/l)
Phenol	44.4%	48.2	38.6	99%	0.39
Cresols	36.6%	39.2	31.4	97%	0.94
Xylenol	14.3%	15.6	12.5	97%	0.38
C_3-phenols	1.4%	3.6	2.9	97%	0.09
Total		106.6	85.4		1.8

* Distribution in foul process water from the Synthane process.

**This assumes that wastewater from phenol recovery is diluted by decanter wastewater with respect to phenol.

mode at the time of sampling. Feed coal was a Kentucky high-sulfur bituminous.

The PAH concentrations in the raw wastewater are present at concentrations below MATE values even prior to any treatment or dilution with wastewater low in TOC or COD, as is evidenced by the fact that all degree-of-hazard values are less than one. The degradability of PAH in activated sludge is expected to be highly variable. Assuming 30 to 80 percent degradation unless otherwise noted in Table 3-17 and accounting for a minimum dilution of 1.25 (decanter wastewater from hydrotreating), bio-effluent concentrations are estimated in Table 3-17.

TABLE 3-17. CONCENTRATIONS OF PAH IN SRC FOUL PROCESS WATER (11)

Compound	Concentration (ppm)	MATE µg/l	Degree of Hazard (Health)	Bio-Unit Effluent* (ppm)
PAH				
Methylindane	15			2.4-8.4
Tetralin	0.1	1×10^{3}	0.1	0.05 (15%)[b]
Dimethyltetralin	0.5			0.08-0.4
Naphthalene	5	7.5×10^{5}	6.6×10^{-3}	0.81 (80%)[a]
Dimethylnaphthalene	0.3-2	3.38×10^{6}	8.9×10^{-5} -5.9×10^{-4}	0.05-1.12
2-Isopropylnaphthalene	0.7	3.38×10^{6}	2.1×10^{-4}	0.11-0.39
1-Isopropylnaphthalene	2			0.32-1.12
Biphenyl	0.2	1.5×10^{4}	0.01	0.03-0.11
Acenaphthalene	< 0.1			0.01-0.06
Dimethylbiphenyl	0.2-0.5			0.79-1.1
Dibenzofuran	0.6			0.09-0.32
Xanthene	0.1			0.01-0.06
Dibenzothiophene	1.5			0.24 (60%)[a]
Methyldibenzothiophene	<0.1			0.01-0.06
Thioxanthene	0.1			0.01-0.06
Fluorene	0.3			0.08 (64%)[a]
9-Methylfluorene	0.3			0.05-0.17
1-Methylfluorene	0.2			0.04 (76%)[a]
Anthracene/Phenanthrene	1.1	8.4×10^{3}/ 2.4×10^{4}	0.13/0.049	0.26 (70%)[b]
Methylphenanthrene	0.2-0.3			0.05-0.11
C_2-Anthracene	<0.05			0.01 (62%)[a]
Fluoranthene	0.4	1.4×10^{6}	2.9×10^{-4}	0.06-0.63
Dihydropyrene	<0.05			0.007-0.03
Pyrene	0.6	3.45×10^{6}	1.7×10^{-4}	0.24 (50%)[a]
Dimethyldibenzothiophene	<0.05			0.007-0.03

[a] Removal efficiencies for a sludge degrading petrochemicals in Colgate Creek, South Louisiana (18).

[b] Isolated organisms known to degrade naphthalene and/or phenanthrene (19).

*A 30-80 percent degradation is assumed unless otherwise noted.

3.2.2.3 Straight-Chain Hydrocarbons

Long-chain alkanes and fatty acids have been detected in process wastewater from several coal conversion processes. MEGs have not been assigned to long-chain fatty acids or to long-chain alkanes to date. Long-chain alkanes detected in the SRC foul water are shown in Table 3-17. Straight-chain alkanes from crude oil have been found to be degraded about 96.4 percent by microorganisms isolated from the Chesapeake Bay (19), as follows:

TABLE 3-18. CONCENTRATIONS OF STRAIGHT-CHAIN ALKANES IN CHESAPEAKE BAY MICROORGANISMS

Compound	Concentration (mg/l)
n-octane	2.3
n-undecane	0.3
n-dodecane	0.3
n-tridecane	0.4
n-pentadecane	0.2
n-hexadecane	0.2
n-heptadecane	0.02
n-tetradecane	0.3

Very low concentrations of long-chain alkanes can be expected in the bio-effluent. Fatty acids have been observed in process condensate from Synthane, COED (13), and EDS processes (20). Fatty acids have not been reported in SRC foul water to date. Low toxicity [MATE = 3.8×10^5 μg/l (health) for acetic acid] and high rate of biodegradation suggest that these compounds warrant no concern in process effluent.

3.2.2.4 Heterocyclic N-Aromatics

Table 3-19 shows concentrations of polycyclic N-aromatics observed in the process wastewater from the Synthane gasification process.

TABLE 3-17. CONCENTRATIONS OF PAH IN SRC FOUL PROCESS WATER (11)

Compound	Concentration (ppm)	MATE µg/l	Degree of Hazard (Health)	Bio-Unit Effluent* (ppm)
PAH				
Methylindane	15			2.4-8.4
Tetralin	0.1	1×10^3	0.1	0.05 (15%)[b]
Dimethyltetralin	0.5			0.08-0.4
Naphthalene	5	7.5×10^5	6.6×10^{-3}	0.81 (80%)[a]
Dimethylnaphthalene	0.3-2	3.38×10^6	8.9×10^{-5} -5.9×10^{-4}	0.05-1.12
2-Isopropylnaphthalene	0.7	3.38×10^6	2.1×10^{-4}	0.11-0.39
1-Isopropylnaphthalene	2			0.32-1.12
Biphenyl	0.2	1.5×10^4	0.01	0.03-0.11
Acenaphthalene	< 0.1			0.01-0.06
Dimethylbiphenyl	0.2-0.5			0.79-1.1
Dibenzofuran	0.6			0.09-0.32
Xanthene	0.1			0.01-0.06
Dibenzothiophene	1.5			0.24 (60%)[a]
Methyldibenzothiophene	<0.1			0.01-0.06
Thioxanthene	0.1			0.01-0.06
Fluorene	0.3			0.08 (64%)[a]
9-Methylfluorene	0.3			0.05-0.17
1-Methylfluorene	0.2			0.04 (76%)[a]
Anthracene/Phenanthrene	1.1	8.4×10^3/ 2.4×10^4	0.13/0.049	0.26 (70%)[b]
Methylphenanthrene	0.2-0.3			0.05-0.11
C_2-Anthracene	<0.05			0.01 (62%)[a]
Fluoranthene	0.4	1.4×10^6	2.9×10^{-4}	0.06-0.63
Dihydropyrene	<0.05			0.007-0.03
Pyrene	0.6	3.45×10^6	1.7×10^{-4}	0.24 (50%)[a]
Dimethyldibenzothiophene	<0.05			0.007-0.03

[a] Removal efficiencies for a sludge degrading petrochemicals in Colgate Creek, South Louisiana (18).

[b] Isolated organisms known to degrade naphthalene and/or phenanthrene (19).

*A 30-80 percent degradation is assumed unless otherwise noted.

TABLE 3-19. CONCENTRATIONS OF HETEROCYCLIC N-AROMATICS DETECTED IN SYNTHANE FOUL PROCESS WATER (12)

Compound	Concentration mg/l	MATE mg/l
Quinoline	0-100	2.4×10^2
Methylquinoline		8.3×10^2
Dimethylquinoline		
Ethylquinoline		
Benzoquinoline		
Methylbenzoquinoline		
Tetrahydroquinoline		
Isoquinoline	0-110	2.4×10^2
Indole		1.7×10^2
Methylindole		
Dimethylindole		
Benzoindole		
Methylbenzoindole		

The values represent ranges observed in gasification using six different coal types and different operating conditions. All of the heterocyclic N-aromatics shown in Table 3-19 have been detected in the SRC process wastewater, but have not been quantified to date. The treatment of N-polycyclics by activated sludge and by activated carbon is variable. However, for those compounds in Table 3-19 for which MATE values have been derived, the degree of hazard (health) is less than one in every case, when it is assumed that the total concentration of heterocyclic N-aromatics is attributable to that compound alone.

Several of these compounds will be further reduced in biological treatment. Singer and coworkers (21) have investigated the biological treatability of heterocyclic N-aromatics. Oxygen depletion of 5 mg/l of the compounds was as follows after a 20-day incubation period (toxic implies the compound killed the organisms responsible for degradation):

TABLE 3-20. OXYGEN DEPLETION OF HETEROCYCLIC N-AROMATICS

Compound	O_2 depletion (percent)
Quinoline	82
2-methylquinoline	80
4-methylquinoline	Toxic
indole	79
2-methylindole	Toxic
3-methylindole	85

3.2.2.5 Polycyclic Hydroxy Compounds

The quantities of polycyclic hydroxy compounds shown in Table 3-21 were average ranges for six different Synthane operations using different coal types. Polycyclic hydroxy compounds have not been reported to date in the SRC process wastewater. If one assumes that benzene is the solvent used in phenol recovery, one can expect that recovery of dihydric phenols will be quite complete, insofar as the distribution coefficient is greater for dihydric phenols than it is for monohydric phenols.

3.2.2.6 Trace Elements

Several streams within the SRC process can be characterized with respect to concentrations of various trace elements. Several streams, as was mentioned under complex effluents, are treated by settling ponds only. Those streams which have significant trace element constituents and are treated in the wastewater treatment module include the foul process condensate and decanter water from hydrotreating. The trace element composition of decanter wastewater is not known at the present time. As a first approximation of the trace element composition of the foul water, data for the H-Coal PDU will be used (Table 3-22) (14).

TABLE 3-21. CONCENTRATIONS OF POLYCYCLIC HYDROXY COMPOUNDS FOUND IN FOUL PROCESS WATER FROM SYNTHANE PROCESS (13)

	Before treatment (ppm)	After 99% recovery of phenols (ppm)
γ-Naphthol	30-290	0.3-2.9
β-Naphthol	30-290	
Methylnaphthol	30-290	
Indenol	20-110	0.2-1.1
C_1-Indenol	20-110	
4-Indanol	40-150	0.4-1.5
C_1-Indanol	40-150	

TABLE 3-22. TRACE ELEMENT COMPOSITION OF H-COAL FOUL PROCESS CONDENSATE WATER (14)

Component	Conc. mg/1	Degree of hazard (health)	Percent removal required to reach MATE_{WH}
Phosphate	2.1	-	-
Cr	0.1	0.4	0
Cyanide	10*	20	95
Cd	0.8	16	94
Fe	1.2	4.8	79
Pb	2.9	11.6	91
Al	2.5	0.031	0
Cu	0.4	0.80	0
Mg	0.7	0.008	0
Ni	1.7	7.39	86
Ca	4.3	0.018	0
V	1.0	0.13	0
Ti	1.0	0.011	0
Na	10.5	0.013	0
Mo	<0.5	0.007	0
Co	1.4	5.6	82

*This value has been reported for SRC sour water.

As indicated by these data, several metals would have to be removed in the wastewater treatment to reduce the degree of hazard to less than one. As was previously noted under complex effluents, most trace elements in this stream are present in the dissolved state. How they behave in wastewater treatment is not well known. The treatability of these trace elements needs to be further investigated. Often concentrations of trace elements remaining in effluents are higher than is predicted by the solubility product alone, due either to incomplete precipitation or to the presence of finely divided colloidal particles. Table 3-23 shows estimates of the removal efficiency for several trace elements by precipitation and carbon adsorption. Trace element concentrations will be further reduced in biological treatment.

TABLE 3-23. SUMMARY OF REMOVAL OF METALS BY CHEMICAL CLARIFICATION AND CARBON ADSORPTION (22)

Percent removal	Lime system	Ferric chloride system	Alum system
<50	Mo	Co, Tl	Mo, Tl, Zn, Mn, Ni
50-90	Sb, Se*	Mo, Sb, Se	Co, Cd, Sb, Se
90-95	Hg, Sn, Tl, V	Ti	Sn, Ba
95-100	Ag, Be, Bi, Co, Se,** Ti	Ag, Be, Bi, Hg, Sn, V	Ag, Be, Bi, Hg, Ti, V, Cr, Cu, Pb

* Initial concentration - 0.06 mg/l.
**Initial concentration - 0.5 mg/l.

3.2.2.6.1 Cooling Tower Blowdown

The cooling tower blowdown can be expected to contain the same constituents that are present in the raw water. The composition of raw water in White County is typified in

Chapter 4 of this report. The concentration of trace elements in the blowdown depends upon the frequency of purge; and the chemicals used for corrosion inhibition, anti-fouling, etc. It is not anticipated that dissolved solids from the cooling tower blowdown will present any problem, if the purge stream is treated in a side-stream ion-exchange or reverse osmosis process. The feasibility of these methods needs further investigation.

Non-oxidizing biocides used to control growth of slime, algae, and fungi are obviously toxic and cannot be discharged directly. Since ion exchange or reverse osmosis are the treatment methods recommended, it is best to choose a biocide which can be neutralized chemically.

3.2.2.6.2 Coal Pile Runoff

Coal pile runoff results when moisture comes in contact with stockpile coal. The quantity and quality of coal pile runoff can be highly variable and this is reflected in the wide range of concentrations reported for several parameters monitored in coal pile runoff in Table 3-14.

The quality and quantity of runoff is a function of:

- Drainage area
- Stockpile configuration and volume
- Intensity of precipitation
- Particle size
- Reaction time
- Density and slope of the pile.

Stored coal exposed to moisture and air results in the oxidation of metallic sulfides in the coal. Minerals are dissolving in the coal pile even when no precipitation is

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- Stockpile configuration and volume
- Intensity of precipitation
- Particle size
- Reaction time
- Density and slope of the pile.

Stored coal exposed to moisture and air results in the oxidation of metallic sulfides in the coal. Minerals are dissolving in the coal pile even when no precipitation is occurring. With sufficient precipitation most minerals are flushed, and following the first flush only minor constituents are lost (23).

The runoff can be related to rainfall intensity by the following formula:

$$Q = CiA$$

where:

Q = peak runoff rate

C = runoff coefficient and depends upon the drainage area

i = average rainfall intensity

A = drainage area

The Standards of Practice Manual (1) has designated 3.2 hectares for the coal storage area. It has recommended application of a polymer coating to prevent runoff. With an average rainfall of 1.06 m/hr in the state of Illinois and a runoff coefficient assumed to be 0.7, 67.1 Mg/day of relatively clean runoff could be expected with the polymer coating. No data are available on the composition of runoff when a polymer coating is applied.

If a similar runoff coefficient were found for a coal pile without a polymer coating, the plant would need to handle the highly contaminated runoff in settling ponds. Table 3-14 shows coal pile drainage characteristics for several plants; the wide variation in concentrations for the parameters shown suggests the need for site-specific monitoring. With or without the use of polymer, runoff should be collected in settling ponds and allowed a retention time sufficient to settle out most suspended solids. This water would be reused in coal preparation. Since the water will be reused rather than discharged to surface streams, the major concern is groundwater contamination and/or overflow from the settling basin. Impervious lining (e.g., bentonite clay) in the settling pond is essential to prevent soluble species from reaching the aquifer. Basins should be made available outside the settling ponds to collect overflow.

3.2.2.6.3 Refuse Pile Runoff

Many of the same variables influencing the quality of coal pile runoff also affect the quality of refuse pile runoff. In the case of the refuse pile, however, sealing techniques will be used to reduce the amount of moisture infiltration and subsequent leaching of coal refuse material.

Data in Table 3-24 show refuse pile runoff from a bituminous coal refuse pile covered with clay and grass and, for comparison, a refuse effluent from a pile which was not covered (24).

It is quite evident from the data that runoff from an uncovered refuse pile would pose serious threats; the data showed that the concentration of iron and SO_4 increases 4,466 and 18.7 times, respectively, and that the stream adjacent to the refuse pile was extremely acidic.

3.2.2.6.4 Mineral Residue Leachate

In the conceptual design advocated in the Standards of Practice Manual (1) some 3,705 Mg/day of residue will not be

TABLE 3-24. EFFECTS OF REFUSE PILE RUNOFF ON STREAM COMPOSITION (24)

	Pile covered with clay and grass		Pile with no cover	
Stream component	Above pile (mg/1)	Below pile (mg/1)	Above pile (mg/1)	Below pile (mg/1)
Total acidity	0	0	-	5,660
pH	7.5	7.5	7.9	2.9
SO_4	106	106	564	10,544
Na	16	16	20	256
Mg	35	35	No Data	No Data
Al	1.0	1.0	No Data	No Data
K	2.2	2.5	No Data	No Data
Ca	70	70	No Data	No Data
Mn	0.01	0.01	0.03	10
Fe	0.1	0.1	0.5	2,233

utilized in the gasifier to produce hydrogen. It is not likely that these huge quantities of hazardous material would be disposed of as such. Rather, the heating value of the remaining residue should be recovered and sold to outside sources if it cannot be used for process fuel gas. Because the residue will be further used, leachate should not be a problem except over short-term storage time. It has been observed during the process of leachate studies (25) that the SRC residue, because of its high carbon content, did not leach readily and failed to dissolve in mineral acids.

3.2.2.6.5 Ash Ponds

Coal utilized in the steam generation module is anticipated to generate roughly 66 Mg/day of bottom ash and 36.6 Mg/day of particulates in the stack gas. The fly ash will be collected in hoppers below the mechanical collectors or electrostatic precipitators. It is expected that the ash will be mixed with a high-velocity water jet, and then sluiced through cast-iron alloy pipes to a settling pond. Bottom ash is removed from the bottom of the boiler using a high-pressure spray system. This ash-water mixture will also be pumped to the settling pond. Alternatively, the ashes could be hauled off-site to the stripped mine, which would eliminate any pollution potential from the ash ponds.

The characteristics of the ash pond are not only affected by the coal type but also by the quality and quantity of water used for sluicing.

The data in Table 3-15 show characteristics of once-through ash pond discharges for coal-fired plants using coal from western Kentucky or southern Illinois (17). Ash pond effluents from plants that received coal from western Kentucky and southern Illinois are alkaline.

3.2.2.6.6 Leachate From Slag

The leachability of slag generated by Koppers-Totzek needs to be investigated. It is anticipated that the slag will behave as bottom ash and, as such, will not leach readily.

Slag could ultimately be disposed of in the strip mine, and bottoms from the ash pond are likely to be disposed with the slag.

3.2.2.7 Ammonia

Ammonia is recovered from the foul process water, decanter wastewater, and wastewater from cryogenic separation. Ninety-nine percent ammonia recovery has been assumed in the Standards of Practice Manual (1); at this efficiency the wastewater discharged from ammonia recovery contains 239 mg/l. It is likely that the ammonia will be stripped down to the ammonia-nitrogen requirements for biological treatment.

3.3 Solid Wastes

3.3.1 Land-Destined Wastes

Resolution of solid waste problems involves determining the composition and quantities of solid wastes generated in the liquefaction process, whereupon the most effective control technology available for control of secondary pollutants in the form of leachate, fugitive dust, or runoff is determined.

As air and water pollution regulations are implemented, sludges and slurries which are toxic and/or hazardous are generated in increasingly large quantities. It is assumed for this discussion that most of the solid wastes generated will be disposed of by landfilling; this means of disposal is advocated both in the Standards of Practice Manual (1) and in the Environmental Overview of the Commercial SRC-II Plant (5).

The hazardous nature of the wastes warrants that the following considerations be made prior to disposal of the wastes:

- Chemical stabilization of the solids singularly or in mixture

- Examination of physical/chemical reactions of sludges and slurries in mixture

- Compatibility of liners (e.g., bentonite clay) and containers with the particular hazardous waste

- Compatibility of soils with the hazardous waste where no liners are used.

The very nature of solid wastes suggests a complex mixture of organics and/or trace elements. Table 3-25 lists quantities of solid wastes estimated for a commercial liquefaction facility, and the assumed fate of the solids in treatment/disposal. Fugitive emissions which escape pollution control have been considered under air emissions.

3.3.2 Individual Pollutants from Modules

3.3.2.1 Coal Pile Refuse

Refuse generated in coal preparation consists of refuse from reclaiming and crushing, which consists of tramp iron, slate, coal, and "bone." Refuse from pulverizing and drying contains slate, "bone," coal, and water. The total waste generated amounts to some 7,713 Mg/day with a moisture content of 24 percent. Refuse generated consists of materials ranging from colloidal size to 30 cm long (8).

It is not possible to develop a typical profile for refuse dumps. The chief concern is actually pollutant discharge in the form of fugitive emission and runoff or of leachate as previously discussed.

At a minimum, the following control methods should be practiced in containing refuse:

TABLE 3-25. SOLID WASTES GENERATED IN SRC-II

Solid Waste	Quantity Mg/day	Nature and Fate of the Waste
Coal Preparation		
Coal refuse and tramp iron	7,713	Contains bone, coal, tramp iron and water which is stockpiled and finally disposed of in the mine. Colloidal in size up to 30 cm long.
Dusts removed from pollution equipment from receiving crushing & reclaiming and dryer stack gas controlled	43	Particulates greater than 5μ and a percentage of particulates in 1-5μ range. Dusts are collected in hoppers, wetted and hauled to strip mine.
Dust from receiving crushing and reclaiming uncontrolled	0.015- 0.22	Highly variable; high grain loading particle size 1-100 microns
Dust from dryer stack gas - uncontrolled	0.029- 0.435	High temperature, pressure and flow rate; high moisture content
Hydrotreating		
Spent catalyst	4.25 m^3	Likely to be cobalt-molybdate catalyst - contaminated with metals, sulfur and nitrogen compounds; 3-year life-time
Solid Separation		
Residue	3,705	Heavy product, ash (64%) and undissolved coal (27-28% carbon) should be further processed to recover energy
Hydrogen Production Slag		
Slag (40% water)	1,538	Granular in nature, containing little or no leachable materials or dust. To be transported to strip mine.

(continued)

TABLE 3-25. (continued)

Solid Waste	Quantity Mg/day	Nature and Fate of the Waste
CO_2 shift catalyst		Contaminated with trace element, nitrogen and sulfur compounds; 1-year life time.
Sulfur Recovery		
Particulates in flue gas	4.0	Probably similar in composition to fly ash.
Recovered sulfur by-product	444	Particle sizes are unknown; rich in trace elements; could be stored as a liquid to avoid dust problems
Raw Water Treatment		
Sludge (5% solids)	370	Lime sludge from which it is probably cost-effective to recover the lime before sludge disposal
Steam Generation		
Bottom ash	66	Contains trace elements not volatilized in the combustion zone. Rich in Al, Ba, Ca, Ce, Co, Fe, Mg, Mn, Sc, Th, K.
Fly ash	36.1	Contains some nonvolatile trace elements but is more enriched with the volatile elements (As, Sb, Ni...)
Emitted particulates	0.49	Particles 1 micron in size rich in As, Sb, Cr, Cd, Ni, Pb, Se, Ti, & Zn

(continued)

TABLE 3-25. (continued)

Solid Waste	Quantity Mg/day	Nature and Fate of the Waste
Wastewater Treatment		
Surge tank bottoms	Not quantified	Oily sludges, much of which can be recovered and reprocessed through the plant
Chromate reduction unit sludge	Not quantified	Largely a zinc sulfide and trivalent chrome/ferric hydroxide complex which has precipitated out.
Biological sludge	0.5-0.6	Excess biological solids; 5% solids prior to dewatering. May be chemically treated and landfilled or incinerated.

- The material is to be compacted to reduce air voids

- A sealant, plastic, clay, or cementing agent should be placed over the pile

Ultimate disposal of coal refuse will probably consist of disposal in the strip mines with the slag and fly ash from gasification.

3.3.2.2 Dust Collected by Air Pollution Equipment in Coal Preparation

It has been estimated that about 50 Mg/day of coal dust is collected by air pollution abatement equipment in coal preparation. This dust must be handled without creating new air pollution problems. A trickle valve or rotary valve may be connected to discharge to a screw conveyor which collects dust from several hoppers and transfers it to a common collecting point. The dust is then sent to the reactor for liquefaction along with raw coal.

There is no quantification of the amount of dust which escapes during the disposal operation. The dust composition will be similar to the parent coal, although certain trace elements have a tendency to concentrate in smaller particles.

3.3.2.3 Sulfur

The Standards of Practice Manual (1) has determined the quantity of by-product sulfur to be 444 Mg/day. The sulfur recovered in the process is expected to have a trace element composition similar to that shown in Table 3-5. This sulfur was recovered from a high-sulfur Kentucky bituminous coal whose trace element analysis differs from Illinois #6 coal. It is estimated that roughly 1.6 percent of the total trace element content is found in the recovered sulfur (3); however, certain trace elements (e.g., vanadium) are present as the result of sulfur recovery. The hazardous nature of this by-product warrants that it be stored properly to avoid fugitive emissions (25). The recovered sulfur may be handled and stored as a liquid in completely closed containers to avoid emissions.

In addition to the hazard presented by the sulfur by-product itself (due in part to the possible explosion and trace element content), there is a continuous purge stream from the Stretford unit. It is recommended that this purge stream be decomposed by high-temperature hydrolysis (1). This will recover vanadium in solid form along with some sodium carbonate, sodium sulfide, and sodium sulfate.

Hydrogen cyanide is converted to CO_2, H_2O, and N_2, and sodium thiosulfate is converted to H_2S and H_2O. This purge stream has the following composition:

TABLE 3-26. ABSORBENT PURGE FROM THE STRETFORD UNIT (1)

Compound	g/Mg of coal	Total Mg/day
$Na_2S_2O_3$	68.1	1.53
NaCNS	28.0	0.63
$NaVO_3$	4.13	0.096
ADA*	7.02	0.15
Na_2CO_3, $NaHCO_3$	19.0	0.43
H_2O	503.9	11.36
TOTAL	630.2	14.19

*Salt of anthraquinone acid.

3.3.2.4 Sludges

The sludges generated in the SRC facility are generally hazardous wastes and must be disposed of accordingly. This discussion will consider the following sludges:

- Surge tank bottoms
- Bottom sediment from API separator and chemical coagulation unit
- Froth skimmed from air-flotation unit
- Bio-unit sludge
- Chromate reduction unit sludge
- Raw water treatment sludge
- Desulfurization sludge.

There are several control/disposal options considered in the Standards of Practice Manual (1). Landfilling is presently the most attractive for the large quantities of sludge generated. A high-pressure sludge dewatering system will be needed to convert the sludges into a filter cake suitable for disposal.

3.3.2.4.1 Surge Tank Bottoms

Residence time in the surge tank must be sufficient to allow for settling of heavy sediment. In the case of the surge tank utilized at the SRC pilot plant, much of the heavy oil which accumulated on the bottom can be recovered.

However, an unquantified amount which must be disposed forms a stable emulsion with oil (26).

3.3.2.4.2 API Separator Bottoms/Clarifier

The residence time required for gravity phase separation is sufficient to allow heavy sediment in the water to settle to the bottom.

The quantity of API separator bottoms may be highly variable. On the basis of information from several sources, it can be expected that the waste sludge from API separator plus secondary treatment facilities will contain 180 to 720 g of dry solids/m^3 of water treated (22). The wet sludge composition will be approximately 1 to 3 wt percent dry solids, 10 to 30 wt percent oil and 65 to 90 wt percent water. One source reports 180 g of dry solids/m^3 of effluent from API separation plus chemical coagulation. The source also reports a range of 0.01 to 0.09 Mg/day from API separation alone (27).

Much of the oil in the API separator bottoms can be recovered and reprocessed. The heavy sludge can be heated in a treater to which demulsifying chemicals have been added. The contents are allowed to settle, and the oil layer is subsequently removed. Alternatively, API separators and surge tank bottoms may be treated with precoat vacuum filtration or centrifugation to recover some of the oil.

A profile of a refinery sludge from the API separator is shown in Table 3-27.

TABLE 3-27. COMPOSITION OF API SEPARATOR BOTTOMS (28)

Component	Quantity	Component	Quantity
Total solids (%)	21.	Cu (ppm)	3,500
Total volatile solids (%)	31.	Fe (ppm)	5,560
Moisture (%)	79.	Hg (ppm)	10.6
As (ppm)	1.	Ni (ppm)	23.
B (ppm)	7.2	Pb (ppm)	182.
Be (ppm)	4.8	Se (ppm)	26.
Cd (ppm)	.5	Asbestos (fibers/100 g)	3.
Cl (%)	2.35	Fibers (fibers/100 g)	40.
Cr (ppm)	125.		

3.3.2.4.3 Air Flotation Skimmings

In the air flotation unit remaining suspended solids and entrained oils from the process wastewater are removed. The concentration of air flotation skimmings is approximately 0.25 percent solids (by wt.) (29). It is unlikely that this sludge will be disposed as such. Rather, the skimmings will be sent through a series of hot and cold settling in which most of the oil and water are recovered. There will be a small but unquantified amount of unresolved emulsions after treating.

3.3.2.4.4 Activated Sludge

An estimation of sludge production is based upon design data which make the following assumptions:

- 0.48 g of VSS/g BOD removed (27)

- BOD removal of 200 ppm (wt.)

- Volatile solids concentration of waste sludge equals 70 percent.

For a wastewater treatment system receiving 1.0 to 1.2 x 10^3 m^3/day, one can expect roughly 0.54 to 0.65 Mg/day of sludge.

An analysis of bio-unit sludge from the SRC pilot plant shows very high levels of trace elements. A sludge profile (Table 3-28) was derived by assuming that the concentration factor as given by (3):

$$\frac{\text{trace element concentration in sludge}}{\text{trace element concentration in raw coal}}$$

is the same for Illinois No. 6 as it was for a Kentucky bituminous coal from which the original analysis was made (1).

TABLE 3-28. TRACE ELEMENT CONCENTRATION IN BIO-UNIT SLUDGE (3)

Element	Concentration (ppb)	Degree of hazard (health)
As	5.7	0.01
Sb	1.6	0.00
Se	6.9	0.07
Hg	13,936.	697
Br	28.2	0.00
Ni	17.7	0.039
Co	5.0	0.00
Cr	69.1	0.14
Na	463.9	0.03
Rb	10.6	0.01
Cs	0.34	0.00
K	219.4	----

The bio-unit sludge has not yet been characterized with respect to organics.

There are several disposal options for oily and biological sludge.

- Wet oxidation--this method involves chemical oxidation with air in an aqueous phase reaction at 200 to 300°C and 1,200 to 1,800 psig. It is capable of reducing the sludge total solids by about 70 percent, reducing volatile solids by about 85 to 90 percent, and reducing COD by about 80 to 85 percent (27).
- Sludge dewatering and disposal--where land disposal of sludge is the chosen option, the sludge will require dewatering. Mechanical sludge thickeners will increase the sludge solids content to 5 to 10 percent by weight. Centrifuges can be used to concentrate the solids to 20 to 30 percent by weight and vacuum filters may achieve 40 to 60 percent by weight of solids (27). The requirements for chemically stabilizing the dewatered sludge need to be investigated.
- Incineration--the fuel value of the biological sludge should be investigated to determine if substantial amounts of energy could be recovered by incineration.

3.3.2.4.5 Chromate Reduction Unit Sludge

Corrosion inhibitors used in the cooling tower will be assumed to be hexavalent chromium, zinc, and phosphonate. A chromate reduction unit will be required to remove the chromium from the cooling tower blowdown. The discharge from this unit contains zinc sulfide and trivalent chrome/ferric hydroxide complex which has precipitated out. These compounds are difficult to settle and will require use of a coagulant aid. The concentration of chromate required for corrosion inhibitor can be reduced by adding zinc and phosphonate (30). The following additives are assumed:

Chromate	20-25 ppm
Zinc	2-5 ppm
Phosphonate	[Dosage sufficient to act as a metal passivator and scale inhibitor (20-50 ppm)] (30)

The wastewater treatment sludges may be combined and chemically conditioned to improve dewatering characteristics. The final filter cake will most likely be landfilled.

3.3.2.4.6 Raw Water Treatment Sludge

Raw water requirements for the commercial SRC facility amount to 31,711 m^3/day for a facility in which the process water is recirculated, and roughly 36,280 m^3/day for a once-through system. The major waste stream discharged from the raw water treatment facility is sludge removed from the clarifiers. The raw water is treated with lime and sodium carbonate and the resultant sludge is characterized as follows (1):

TABLE 3-29. RAW WATER TREATMENT SLUDGE

Component	Recirculated process water (Mg/day)	Once-through system (Mg/day)
Water	351.6	402.2
$CaCO_3$	16.0	18.3
$Mg(OH)_2$	0.9	1.0
$Ca_5(OH)(CO_4)_3$	0.03	0.03
Detergent	0.003	0.003
Suspended solids	1.3	1.5
Totals	369.83 (95% water)	423.03 (95% water)

It is recommended that the lime be recovered from this sludge. The recovery process reduces the moisture content nearly 10 fold. The sludge remaining to be landfilled amounts to 48.5 Mg/day.

It is conceivable that all wastewater sludges would be dewatered and disposed of as a single filter cake. This is an attractive idea from the point of view of disposal problems. However, complex chemical interactions among components of the sludge need to be investigated.

3.3.2.4.7 Ash from Steam Generation

The coal-fired steam generation module will produce 66 Mg/day of bottom ash and 36.1 Mg/day of fly ash. As far as solid waste disposal practices are concerned, the distinction is made because fly ash can contribute serious pollution problems in the form of leachate or fugitive dusts if not handled properly. Table 3-30 estimates the concentrations of several trace elements in the bottom ash and fly

TABLE 3-30. ESTIMATED CONCENTRATION OF TRACE ELEMENTS IN BOTTOM ASH AND FLY ASH FROM STEAM GENERATION (31)*

Component	Bottom ash (ppm)	Fly ash (ppm)
As	29.8	269.
B	298.	15.
Ba	1,413.	3,750.
Be	2.1	27.
Cd	<40.	<151.
Cr	173.	98.9
Cu	170.	595.
F	10,512.	678,816.
Ge	<1.2	51.5
Hg	<0.014	<0.014
Mn	115.	748.
Mo	33.8	122.
Ni	86.9	557.
Pb	180.	720.
Sb	<12.3	53.9
Se	.31	36.7
V	<235.	<235.
Zn	<204.	9,843.

*The ratio of trace elements in bottom or fly ash to the concentration of the same element in coal was used to estimate the concentrations expected in the bottom ash or the fly ash when Illinois No. 6 coal is used.

ash. The ratios of trace elements in coal to trace elements in bottom and fly ash for a particular batch of coal were used to predict concentrations for Illinois No. 6 (31).

Bottom ash is recovered from the "dry bottom" boiler and falls into a hopper filled with water. The ash and water slurry is mixed with the fly ash. The mixture may be piped to settling ponds or dewatered and hauled off-site for disposal. If settling ponds are used, impervious liners (e.g., bentonite) may be required. The high concentration of alkali and alkaline earth elements in Illinois No. 6 coal would tend to give the coal ash solution alkaline reactions. The trace elements tend to form insoluble compounds which, together with solids in the suspension, will tend to fill and seal the pore space in underlying soils. Therefore, the rate of movement of leachate would decrease over an extended period of time. Good disposal practices, however, would probably require liners nevertheless.

3.3.2.4.8 Flue Gas Scrubber Sludges

This sludge stems from flue gas desulfurization of the coal-fired steam generation operation. The residue of a conventional calcium scrubbing process (lime or limestone) is a slurry of mainly calcium sulfite. The slurry is thixotrophic even after dewatering.

The quantity of sludge generated depends upon the type of control, the extent of control required and the load factor for the plant. Table 3-31 shows quantities of sludge generated and sludge characteristics for power plants using different types of sulfur dioxide control systems (32).

Since it has been assumed that the 150 MW/day of electricity required to run the SRC plant will be purchased, the use of coal for utilities is limited to steam generation.

3.3.2.5 Residue

It has been estimated that 3,705 Mg/day of residue will not be used in hydrogen production, due to operational problems resulting from the high ash content of the residue (64 percent) (1). However, the high carbon content of the residue (27 to 28 percent) (33,34), indicates that this solid should be further utilized to recover useful energy.

TABLE 3-31. CHARACTERISTICS OF SCRUBBER SLUDGE GENERATED IN COAL-FIRED POWER PLANTS (32)

Type SO_2 control	Sulfur content	Ash content	Sludge composition - dry basis (wt. %) Mg/D/MWatt	$CaSO_3 \cdot 1/2H_2O$	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	Flyash	Solids content after dewatering
Limestone injection wet scrubber	3.8%	12%	2.05	10	40	5	45	50
Lime scrubber	3.7%	14%	1.82	94	2	0	4	50
Tail-end limestone scrubber	3.5%	15%	2.55	50	15	20	15	35

Since it is unlikely that the residue will be disposed of, as such, the solid waste problem is a temporary one. In an effort to determine the leachability of the residue (25), efforts were made to dissolve the solid in dilute acid. Efforts failed to produce any leachate over the test period. It is not anticipated that temporary storage would cause any significant leaching problems.

Table 3-32 shows the organics quantified in the mineral residue to date. This analysis was performed on a residue derived from Kentucky bituminous coal during operation of SRC-I process. Differences in the organic content of the residue under the operating conditions for SRC-II in this

TABLE 3-32. ORGANICS QUANTIFIED IN SRC-I SOLID RESIDUE FROM KENTUCKY BITUMINOUS COAL (11)

Compound	Concentration (mg/1)	Compound	Concentration (mg/1)
PAH Fraction		Neutral Fraction	
Indane	85	n-undecane	90
Methylindane	40	n-dodecane	550
Dimethylindane	25	n-tridecane	9,100
Tetralin	110	n-tetradecane	210
Dimethyltetralin	35	n-pentadecane	80
6-Methyltetralin	50	n-hexadecane	50
Naphthalene	1,500	n-heptadecane	20
2-Methylnaphthalene	740	n-octadecane	10
1-Methylnaphthalene	180	n-nonadecane	14
Dimethylnaphthalene	470	n-eicosane	14
2-isopropylnaphthalene	2	n-heneicosane	16
1-isopropylnaphthalene	1	n-docosane	14
C_4-naphthalene	15	n-tricosane	14
Cyclohexylbenzene	1	n-tetracosane	10
Biphenyl	5	others	26
Acenaphthylene	270		
Dimethylbiphenyl	61		
Dibenzofuran	60		
Xanthene	20		
Dibenzothiophene	70		
Methyldibenzothiophene	8		
Dimethyldibenzothiophene	20		
Thioxanthene	5		
Fluorene	80		
9-methylfluorene	40		
1-methylfluorene	50		
Anthracene/phenanthrene	500		
Methylphenanthrene	100		
1-methylphenanthrene	50		
C_2-anthracene	10		
Fluoranthene	200		
Dihydropyrene	10		
Pyrene	200		

study cannot be predicted at this time. Table 3-33 shows quantification of the minor elements in the SRC residue. Ratios of:

$$\frac{\text{trace elements in raw coal}}{\text{trace elements in residue}}$$

for Kentucky bituminous coal were used to develop an inorganic profile of the residue derived from operation with Illinois #6.

TABLE 3-33. ESTIMATED TRACE ELEMENT COMPOSITION OF THE SRC RESIDUE (11)

Element	Concentration (ppm)	Element	Concentration (ppm)
Antimony	5.2	Lanthanum	36.8
Arsenic	24.9	Lutetium	2,050.
Barium	579.	Nickel	126.
Bromine	18.8	Samarium	6.1
Calcium	33,323.	Scandium	14.7
Cerium	71.4	Selenium	12.2
Cesium	7.3	Sodium	1,155.
Chromium	178.	Tantalum	0.71
Cobalt	4.1	Thailium	3.5
Copper	8.0	Terbium	0.69
Europium	1.2	Uranium	10.6
Hafnium	2.7	Ytterbium	2.6
Iron	116,760.	Zinc	1,938.

3.3.2.6 Gasifier Slag

One of the large-volume solids to be disposed of in the SRC plant is the gasifier slag and quenched fly ash; this has been estimated at 1,538 Mg/day (40 percent water) (1).

The current design specifications for the treatment of the slag require that it be crushed, slurried with water, and de-ashed. The fly ash from the quencher will be flashed down, neutralized with slaked lime, and thickened (5). It is anticipated that the waste will be disposed of in the strip mine. It is thought that the waste will behave similarly to bottom ash from coal-fired power plants, and consequently will not leach (5). This is an area which requires investigation via leachate studies.

The composition of the waste is fairly predictable. Since both fly ash and slag are disposed of together, it can be assumed that only the very volatile trace elements are lost to the atmosphere. This would include mercury, selenium, germanium, chlorine, and bromine. The trace element composition of clarifier water has been found to be very low (35), and it is not anticipated that large quantities of trace elements will be lost to the wastewater.

One interesting possibility for disposal of some of the other hazardous solid wastes would be encapsulation in the slag. The possibility of injecting dried solids into the molten slag should be investigated.

3.3.3 Non-Chemical Pollutants

3.3.3.1 Noise

Much of the noise pollution problem will be generated within the coal preparation area. High noise levels will be generated from:

- Coal shaker
- Dust collector
- Primary crusher
- Secondary crusher.

While quantification of noise generated awaits sizing of equipment, some estimates may be made. The highest noise levels within the plant can be expected from the coal shaker. The power required to operate one 5.2 Mg shaker generates 110 to 125 dB(A) at 3.3 meters distance (29).

Data on noise generated by coal crushing indicate that primary and secondary coal crushers generate 90 and 95 dB(A), respectively, at a distance of 3.3 meters (29).

Within the process, high noise levels will be generated by:

- Process heaters/boilers
- Compressors
- High-pressure let-down valves
- Reciprocating pumps.

While an accurate assessment of noise will depend upon equipment size, the problem areas in the pilot plant are some indication of noise areas which can be anticipated. The major noise areas were identified as follows (36):

(a) Coal Receiving and Preparation: The major noise-producing equipment comprises the pulverizer (90 to 95 dB(A)), preheater charge pump (95 to 100 dB(A)), gravimetric feeder, vibrator on the roof, and steam release.

(b) Wastewater Treatment Area: The major noise sources are the pumps by the holding tank and balancing tank, and especially the air compressor by the bio-unit, which produces up to 100 dB(A) at about one meter distance.

(c) Dowtherm Heater: Noise was 90 to 95 dB(A) under the Dowtherm heater and 90 to 100 dB(A) around the Dowtherm pump.

(d) Hydrogen Generation Unit: Noise was 95 to 100 dB(A) at the center of the Stretford unit and 90 to 95 dB(A) at the center of the hydrogen unit.

(e) Solids Separation Area: Major noise sources are several pumps, steam releases, and the hammer on the mineral residue dryer. The noise in a large portion of the mineral separation area is in excess of 90 dB(A).

(f) Solvent Recovery Area: Most noises are produced by the many steam release valves and pumps. A good portion of the solvent recovery area is in excess of 90 dB(A).

(g) Boiler House: Noise inside the boiler house ranges from 85 to 95 dB(A).

Noise level contours should be established once the plant is in operation. Equipment may need to be relocated to reduce noise at certain points, and/or noise mitigation may be accomplished by:

- Installing mufflers
- Enclosing or insulating motor cases
- Insulating operating stations
- Adding insulated ducts or mufflers to boilers.

Insofar as the surrounding area is not highly forested, it is anticipated that noise control will be required.

3.3.3.2 Thermal Pollution

Thermal efficiency is a measure of the thermal pollution from a process, in that essentially all heat loss must be dissipated to the environment.

The thermal efficiency of the SRC-II process base design is approximately 74 percent. This assumes that the filter cake is not further treated to recover excess energy. The heating value of input and output materials is shown in Table 3-34.

There are several alternatives which may be considered to improve the thermal efficiency without seriously altering process design, as follows:

- Use waste heat for coal drying.
- Optimize heat balance around the reactor.

TABLE 3-34. THERMAL EFFICIENCY OF SRC-II

Input	Mg/day	Joules/day
Coal to reactor	18,552	552×10^{12}
Coal to gasifier	1,392	41.5×10^{12}
Coal to utilities	940	28.0×10^{12}
Output		
Naphtha	518	20.6×10^{12}
Fuel oil	2,591	105.2×10^{12}
Syncrude	5,527	224.4×10^{12}
By-product clean gas	2,132	110.8×10^{12}
Overall efficiency	-----	74%

- Maximize water reuse after treatment.

- Recover more heat by the use of more heat exchangers, heat pumps and power recovery from high pressure liquids; there is a point at which this will become cost prohibitive, however.

If we assume that the final design will be for a thermal efficiency of 74 percent and that the heating value of feed coal is 29,822 joules/kg, 160×10^2 joules will be lost to the environment on each operating day. Table 3-34 shows the expected thermal efficiency of the commercial SRC-II plant (1).

3.3.3.3 Odor Problems

Pilot plant operations have indicated that there is a typical hydrocarbon-like odor associated with the liquefaction process. Insofar as emissions are not fully controlled, the pilot plant is not a true indication of anticipated odor problems. Since ammonia and sulfur recovery facilities are provided in the process, there is a potential for odors from this area. Unfortunately measurement and identification of odors cannot be accomplished by any standardized procedure.

The possibility exists that under certain meteorological conditions or at a larger scale of operation, odors may drift off-site; however, odors are rarely detected off-site at the Fort Lewis SRC plant.

3.3.3.4 Radioactivity

One can calculate the quantity of the natural radionuclides uranium and thorium (and their daughter isotopes) that are present in the 28,123 Mg of Illinois No. 6 coal used daily in the hypothetical SRC plant, given the total concentration of uranium and thorium in the coal, Table 3-35, Columns 1 and 2. These and other calculations are based on the existence of the condition known as radioactive or secular equilibrium, discussed further in Appendix III. As explained in the appendix, because the assumption can be safely made that a secular equilibrium or steady-state concentration of the decay series shown in Figure 3-1 has been reached, one can calculate the amounts and radioactivity of the various isotopes (and their daughter nuclides) that would be present in 28,123 Mg of coal. These results are given in columns 2 through 4 of Table 3-35 (37,38,39).

The total number of alpha, beta, and gamma emissions per second that would be associated with 28,123 Mg Illinois No. 6 coal (due to the uranium and thorium decay series), along with the average and maximum energy levels (MeV) are

TABLE 3-35. RADIOACTIVITY DUE TO DECAY OF THE URANIUM AND THORIUM SERIES ASSOCIATED WITH 28,123 MG (31,000 T) ILLINOIS NO. 6 COAL

Isotope	Mass[a] (g)	DPS[b] ($\times 10^8$)	mCi[a]	Total in mCi for decay series[c]	Time required for decay to reach steady state (years)
Th^{232}	61,900.	2.5	6.9	69.0	211
U^{238}	44,700.	5.6	14.9	209.0	3.7×10^6
U^{235}	324.	2.6	0.7	7.6	5.0×10^5
Sum =	106,924.	10.7	22.5	285.6	

[a] For the radionuclides in 28,123 Mg of coal consumed per day in the SRC plant.

[b] Disintegrations per second for each isotope of the decay series.

[c] Based on a 10-step disintegration series for thorium-232, 14-step series for uranium-238, and an 11-step series for uranium-235.

shown in Table 3-36. These values can be used to estimate the potential hazards to workers breathing dust particles containing these natural radionuclides (see Chapter 5) (37, 38,39).

3.3.4 Product Spills

Approximately 11,368 Mg/day of product and by-product are produced in the commercial SRC process. These products and by-products must be stored and shipped to buyers. A breakdown in production rates is shown in Table 3-37.

The hazardous nature of these materials requires that every precaution be taken to avoid spills and leaks during storage and shipping. Both preventive measures and recovery/disposal methods are required to avoid the potential environmental disaster of spills. The toxic nature of SRC products

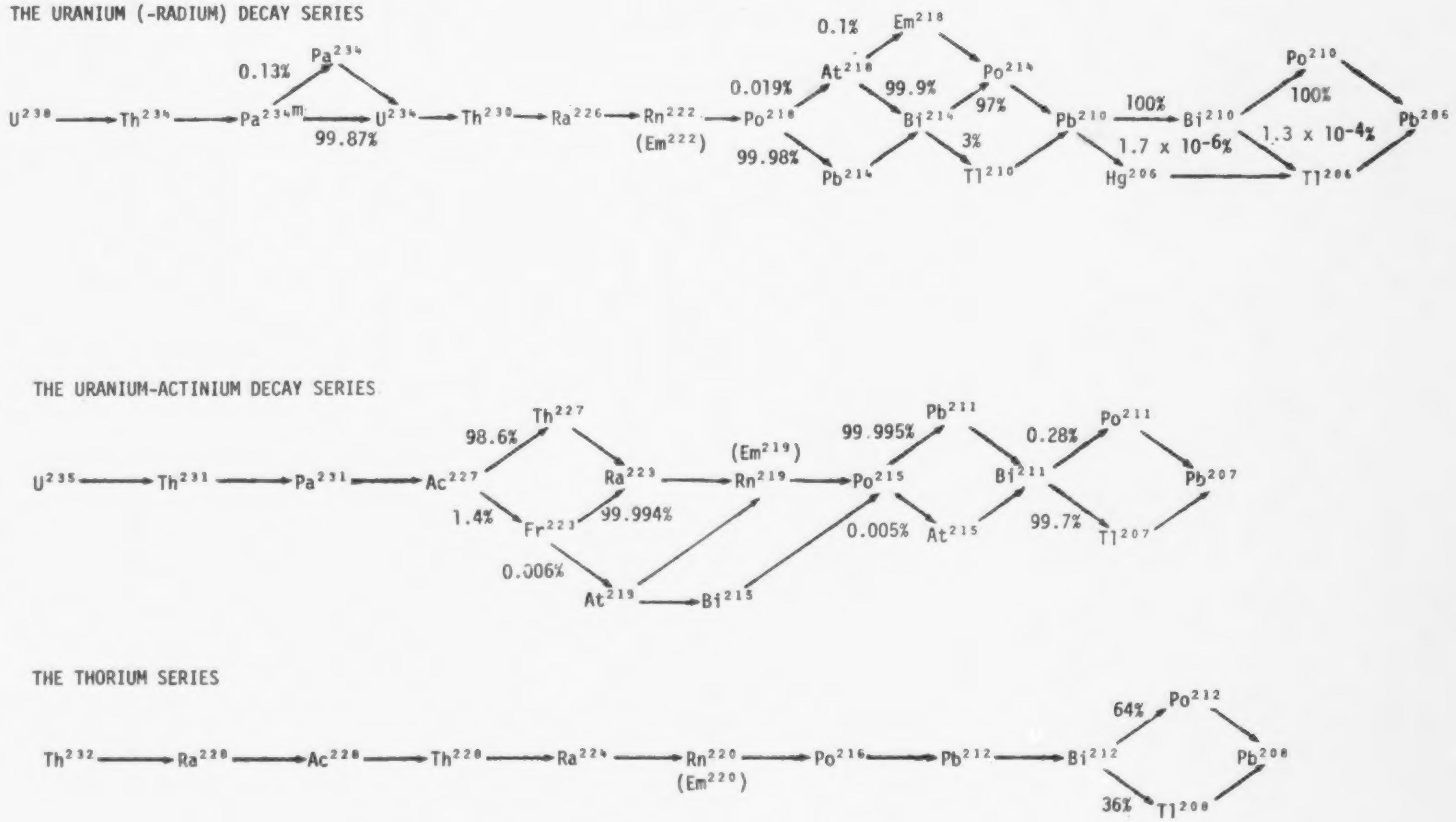
THE URANIUM (-RADIUM) DECAY SERIES
U238
Th234
Pa234m
Pa234
0.13%
U234
99.87%
Th230
Ra226
Rn222
(Em222)
Po218
0.019%
99.98%
At218
0.1%
Em218
99.9%
Pb214
Bi214
Po214
97%
3%
Tl210
Pb210
100%
Bi210
1.7 x 10-6%
Hg206
Po210
100%
1.3 x 10-4%
Tl206
Pb206
THE URANIUM-ACTINIUM DECAY SERIES
U235
Th231
Pa231
Ac227
98.6%
Th227
1.4%
Fr223
Ra223
99.994%
0.006%
At219
Bi215
(Em219)
Rn219
Po215
99.995%
Pb211
0.005%
At215
Bi211
0.28%
Po211
99.7%
Tl207
Pb207
THE THORIUM SERIES
Th232
Ra228
Ac228
Th228
Ra224
Rn220
(Em220)
Po216
Pb212
Bi212
64%
Po212
36%
Tl208
Pb208

Figure 3-1. Decay series for naturally occurring uranium and thorium isotopes

TABLE 3-36. TOTAL RADIOACTIVE EMISSIONS DUE TO THE DECAY OF THE URANIUM AND THORIUM SERIES ASSOCIATED WITH 28,123 MG (31,000 T) ILLINOIS NO. 6 COAL

Series	Emissions	Total produced/sec for 28,123 Mg Illinois #6	Average energy (MeV)	Maximum energy (MeV)
$Th^{232} \rightarrow Pb^{208}$	alpha	1.50×10^9	5.99	8.785+
	beta	1.00×10^9	0.91	2.38
	gamma	6.52×10^8	0.879	2.6146
$U^{238} \rightarrow Pb^{206}$	alpha	4.46×10^9	5.35	7.687
	beta	3.35×10^9	1.04	3.26
	gamma	1.97×10^9	0.550	1.850
$U^{235} \rightarrow Pb^{207}$	alpha	1.82×10^8	5.94	8.01
	beta	9.84×10^7	0.798	1.44
	gamma	1.77×10^8	0.357	1.265
Total U,Th → Pb	alpha	6.14×10^9	5.52	8.785+
	beta	4.45×10^9	1.01	3.26
	gamma	2.80×10^9	0.614	2.6146

TABLE 3-37. COMMERCIAL SRC PROCESS PRODUCTION RATES

Product or By-product (1)	Mg/day (1)
Naphtha	518.2
Fuel oil	2,591.
SRC	5,527.
Ammonia	63.9
Sulfur	442.3
Phenol	34.4
SNG	1,312.
LPG	820.7

can be appreciated from the analysis of products shown in Table 3-38. A complete analysis of products from SRC-II was not available. The analysis shown in Table 3-38 is for the liquefaction of Illinois #6 coal via the H-coal liquefaction process. There are several variables which may affect the products in the SRC-II process somewhat differently, and this needs to be investigated. The use of a catalyst in the H-coal process may increase the degree of hydrogenation and the temperatures in the two reactors are comparable.

3.3.5 Measures to Mitigate Adverse Effects of Syncrude Spills

The several preventative measures that will act to mitigate syncrude spills are as follows:

- Structural integrity must conform to code construction and the materials must be stored in compatible materials.
- Methods to prevent and repair corrosion are needed.
- Periodic examination of tank integrity is required.
- Mobile storage tanks should be isolated from navigable waters.
- Heating coils, where used, must be monitored for oil content; external heating systems rather than internal structural coils should be used.
- Tanks must be gauged carefully before filling to prevent overfill.

TABLE 3-38. INSPECTION OF PRODUCTS FROM ILLINOIS NO. 6 COAL FROM H-COAL PROCESS (35)

Compound	Component	Weight percent	Total weight percent
	C_4-200°C fraction		
1A*: Aliphatic hydrocarbons -- Alkanes and cyclic alkanes (lower boiling)	nC_4	0.10	
	iC_5	0.20	
	nC_5	0.69	
	C_6-C_{12}	11.	
			11.99
	Monocycloparaffins	42.64	
	Dicycloparaffins	8.50	
	Tricycloparaffins	0.19	
			51.33
1B*: Aliphatic hydrocarbons -- alkenes, cyclic alkenes, and dienes (lower boiling)	Monocycloolefins	5.32	
	Dicyloolefins	4.98	
	Tricycloolefins	.90	
			11.20
15* Benzene, substituted Benzene hydrocarbons	C_6 - C_{12}	17.55	
	Indans	6.44	
			23.99
21* Fused polycyclic hydrocarbons	Naphthalenes	0.59	
			0.59
18* Phenols	Phenols (mol. wt) - 108, 122, 136, 150	0.9	
			0.9
			100.0

*MEG category

(continued)

TABLE 3-38. (continued)

Compound	Component	Weight percent	Total weight percent
	200-350° fraction		
1A*: Aliphatic hydrocarbons -- alkanes and cyclic alkanes (intermediate boiling)	n-paraffins	4.8	
	i-paraffins	1.7	
	Monocycloparaffins	14.0	
	Dicycloparaffins	7.9	
	Tricycloparaffins	2.6	
			31.0
1B*: Aliphatic hydrocarbons -- alkenes, cyclic alkenes, and dienes (intermediate boiling)	Monocyclooefins	4.3	
			4.3
15* Benzene, substituted Benzene hydrocarbons	Alkyl benzenes	12.6	
	Indans & tetralins	30.8	
	Indenes	5.7	
	Naphthalenes	3.9	
	Acenaphthenes (C_nH_{2n-14})	4.0	
	Acenaphthenes (C_nH_{2n-16})	2.2	
	Tricyclics (C_nH_{2n-18})	0.4	
			59.6
18* Phenols	Phenols (mol. wt.) - 108, 122, 136, 150, 164, 178	2.0	
			2.0
Other compounds	Other nonhydrocarbons	3.10	
			3.10
			100.00

*MEG category

(continued)

TABLE 3-38. (continued)

Compound	Component	Weight Percent	Total Weight Percent
	350-919°C fraction		
1A*: Aliphatic hydrocarbons -- alkanes and cyclic alkanes (higher boiling)	Paraffins	1.4	
	Monocycloparaffins	3.1	
	Bicycloparaffins	0.6	
	Tricycloparaffins	0.7	
	Tetracycloparaffins	0.4	
	Pentacycloparaffins	0.2	
	Hexacycloparaffins	0.1	
			6.5
1B*: Aliphatic hydrocarbons -- Alkenes, cyclic alkenes, and dienes (higher boiling)	Paraffins	0.0	
	Monocycloparaffins	0.5	
	Bicycloparaffins	0.3	
	Tricycloparaffins	0.2	
	Tetracycloparaffins	0.2	
	Pentacycloparaffins	0.1	
	Hexacycloparaffins	0.1	
			1.4
15* Benzene, substituted benzene hydrocarbons	Phenyls	0.5	
Other compounds	Alkyl benzenes	3.0	
	Indans and/or tetralins	.5	4.0
21* Fused polycyclic hydrocarbons	Other aromatics**	72.8	72.8

*Meg category.

(continued)

TABLE 3-38. (continued)

Compound	Component	Weight percent	Total weight percent
18* Phenols	Phenolic compounds	1.5	1.5
Other compounds	Other nonhydrocarbons	13.8	13.8
			100.0

* MEG category.

**An approximate breakdown of aromatic-type compounds is:

Component type	Millimoles per 100 g
Naphthalenes	93.4
Phenanthrenes	91.1
Chrysenes	21.9
1-2 Benzanthracenes 3-4 Benzaphenanthrenes	14.6
Pyrenes	15.4
5-ring compounds	5.1

- Overflow pipes should be connected to adjacent tanks.

- Relief valves for excessive pressure and vacuum should be in place.

- Inspection methods should concentrate on target areas, including pipeline exposure, pipeline crossing and areas of construction.

- Oil-sensitive probes should be located throughout the drainage system of a potential spill.

If an oil spill does occur within the confines of the plant, it can be expected to be contained. It is required that dikes are provided to contain the maximum spill and that the dikes are covered with an impervious material around each storage tank. In draining these dikes, contaminated waters will be routed to the chemical water sewer.

In the event that storage tanks are undiked, or a spill extends beyond the diked area, a diversion system such as a catchment basin with an oil trap should be available.

A vacuum truck should be permanently assigned to the facility to remove and dispose of spills. In the event that oil should reach the water table, despite all precautions taken, large amounts of the spill could be recovered by pumping.

Ultimately, spills should reach the plant drainage systems. While most of the oil can be reprocessed, the remaining fraction will go through physical/chemical wastewater treatment.

In emergency situations, flammable process material will be released to the flare system. Within this system a knockout drum would retain liquid and send vapors to the flare stack.

3.4 Construction-Related Pollutants

3.4.1 Existing Environmental Requirements

The U.S. Environmental Protection Agency has reported that sediment discharges from construction activities (along with agricultural, silvicultural, and mining) will contribute significantly to water pollution. As a matter of fact, these nonpoint sources will increasingly emerge as the major barrier to meeting the clean water standards promulgated by the state and local governments. Section 208 of the Federal Clean Water Act requires that each state shall plan for and develop best management practices for the control of sediment, nutrients, and other nonpoint source pollutants. As of 1976, 16 states had enacted sediment control laws directly applicable to construction activities. Many county and state statutes require that permits be issued to the constructor before any land disturbances can begin. In some local areas, sediment controls are often coordinated with sewer, grading, and zoning ordinances; flood plain and flood control ordinances; stormwater management and land use regulations; and surface/subsurface drainage regulations.

Both the owner and the constructor of a coal conversion plant must investigate, and be in compliance with, all applicable codes, licenses, permits, and approvals relative to state and local areas, long before the start of the construction work. These codes and permits relate to construction permits, sediment and dust control, noise, wastewater disposal, grading, sanitary facilities, water use, water supply, solid waste disposal, flammable liquid storage, dredged material disposal, easements, fuel storage tanks, dewatering excavation, and building permits. Federal, state, and local agencies to be contacted for these permits and approvals are as shown in Table 3-39 (40).

The National Environmental Policy Act of 1969 (NEPA) requires that every federal agency must prepare a detailed environmental impact statement (EIS) on any proposed action or legislation that could significantly impact the air, water, and land resources (both renewable and non-renewable) of the human environment. Generally, the issuance of a

TABLE 3-39. LICENSES, PERMITS, AND APPROVALS APPLICABLE TO COAL CONVERSION PLANT CONSTRUCTION

Agency	License, permit or approval
U.S. Army Corps of Engineers	- Dredging and construction permit for intake structures in navigable waters
	- Disposal of dredged or fill materials in navigable waters
	- Permit for transmission line crossing of navigable waters
	- Construction permit for barge unloading dolphins
	- Placement of fill in freshwater wetlands contiguous to navigable waters
Federal Aviation Administration	- Notice of Construction of: stacks transmission towers meteorological towers other structures 61 meters above ground
U.S. Environmental Protection Agency, Local Region	- National Pollutant Discharge Elimination System Permit for liquid waste discharge
	- Request for 316(a) and (b) variances from Federal Water Pollution Control Act Amendments of 1972 for once-through cooling discharge and intake
River Basin Commission	- Review and approval of the content of any project which may have a substantial effect on water resources
Bureau of Land Management	- Permit for right-of-way on federal land
	- Permit for test boring on federal land

(continued)

TABLE 3-39. (continued)

Agency	License, permit or approval
U.S. Geological Survey	- Approval of mining plans
U.S. Fish and Wildlife Service	- Approval under Fish and Wildlife Coordination Act in relation to water-related activities. The Department has responsibility to protect and preserve fish and wildlife habitats, conserve fish and wildlife resources, and protect public trust rights of use and enjoyment in and associated with navigable and other waters of the United States
U.S. Department of Agriculture, Forest Service	- Approval of rights-of-way across U.S. Forest Service lands
State Air Pollution Control Commission	- Permit for Construction of Stationary Source of Air Pollutants covering the following anticipated sources: ● Stack discharges (main and auxiliary boilers) ● Coal pile dusting ● Coal handling facilities ● Ash transfer and disposal area ● Open burning of construction refuse ● Concrete batch plant
State Board of Health	- Permit to construct and operate approved sewage disposal and potable water facilities
State Public Service Commission	- Certificate of Public Convenience and Necessity for (1) construction of plant and (2) transmission lines

(continued)

TABLE 3-39. (continued)

Agency	License, permit or approval
State Department of Highways and Transportation	- Construction Permit and franchise for transmission line crossing of roads
	- Permit for highway entrance of plant access road
	- Approval of public road improvements
	- Permits for oversize or overweight vehicles
State Fire Marshal	- Permit to store flammable liquids
	- Approval of facility for fire protection
State Department of Natural Resources & Environmental Control	- Water use and discharge permit for cooling tower make-up and blowdown, including other discharges
	- Test well permit
	- Commercial well permit
	- Permit for dewatering excavation
	- Permit for fuel oil storage tanks
	- Dredging and construction of intake structure
	- Transmission line crossing of water bodies
	- Erosion and sediment control plan
	- State Water Quality Cerification

(continued)

TABLE 3-39. (continued)

Agency	License, permit or approval
	- Construction and operation of the ash disposal area
	- Power plant site permit
	- State EIS
	- Construction Permit for combustion equipment
	- Registration of gaseous emissions
	- Permit to construct a dam
State Planning Office	- Coastal Zone Permit, if required
County Department of Development and Licensing	- Building permit for meteorological tower
	- Building permit for each structure of plant
	- Use and occupancy permits
County Department of Planning	- Rezoning of plant site
	- Approval of transmission line rights-of-way
	- Special exception for meteorological tower
	- Minor subdivision plant approval of roads and plot plan
County Department of Public Works	- Permit for filling or construction operations in flood plains
County Beautification Board	- Construction on public property if required

permit, grant, license, contract, or rights-of-way to a private or federal applicant by an authorizing agency, requires that the applicant submit an environmental report. This technical report is, in reality, a systematic, interdisciplinary effort that includes the following:

- Need for the proposed facility
- Description of the operational and process modules
- Description of the air, water, and land environment as it exists before the proposed facility is constructed
- Analysis of the environmental effects and impacts of the proposed project on the air, water, land, and human resources on a local and regional basis
- Adverse environmental effects and impacts which cannot be avoided, with reference to the air, land, water, human, and economic references
- Mitigation measures used during construction and operation of the plant to protect air, water, and land resources
- Relationship of short-term uses of the environment and its long-term productivity
- Resources committed during plant construction and operation (land, air, water, fuels, human, and economic resources)

- Available alternatives to the proposed action, including choice of site, plant design, and alternative energy sources
- Socioeconomic benefits and costs
- Consultation and communication with state and local planning groups, citizens groups, federal and state regulatory agencies, federal land management agencies, and state and local industrial development groups.

Further details on the preparation of the environmental assessment and the EIS reports can be obtained from the sources listed in References 40, 41, and 42.

3.4.2 Requirements for Erosion and Sediment Control in Illinois

The Illinois Environmental Protection Agency (IEPA) is expected to issue a plan in the spring of 1978 for controlling construction and other nonpoint source pollutants, as mandated by Section 208 of the Federal Water Pollution Control Act (FWPCA). This water quality plan is expected to address the Best Management Practices (BMPs) to reduce erosion and sedimentation resulting from agricultural, construction, mining, and silvicultural activities in the state. The Section 208 water quality plan will also address the problem of urban stormwater runoff.

The following suggestions, made by the Illinois Task Force on Agriculture Nonpoint Sources of Pollution (43), are of interest with respect to the meeting of water quality goals, irrespective of the type of land-disturbing activity:

- Adequate erosion and sediment control will require the installation or application of a system usually involving several conservation practices or measures.

- There usually are several technically adequate alternative conservation systems that could physically be applied to any specific ... planning unit.

- The alternatives that can be applied depend upon factors such as:

  - Soil type characteristics

  - Slope length and steepness

  - Landscape formation (complex vs. smooth slope)

  - Land user's goals, financial assets, and management abilities

  - Land ownership (tenant or landlord) and leasing arrangement (length of lease).

- Development of technical alternatives for a specific planning unit may require the knowledge and skills of a professional soil conservationist.

- The final decision as to which alternative Best Management System will be installed must rest with the land user; the land user will apply and maintain the various components of the system, and is the only person who can realistically make the system operate successfully over a long period of time.

The erosion and sediment control standards in Illinois fall short of those in states that have already enacted sediment control laws directly applicable to construction activities. Although various Illinois agencies have a stake in such controls, their powers are limited. For example, the Soil and Water Conservation Districts offer technical assistance to land developers who may request aid. The Illinois Department of Transportation (IDOT) has established erosion and sediment control standards for state highway construction projects. The IDOT is also responsible for the regulation of all construction in flood plains. Finally, the 1977 amendment to the Illinois Soil and Water Conservation Districts Law, while considered a positive step, did not result in the establishment of comprehensive sediment control requirements directly applicable to construction activity in rural and urban areas of the state.

3.4.3 Sources and Types of Construction-Related Pollutants

Construction work for a coal liquefaction plant can be viewed as a series of relatively short-term environmental disturbances, in contrast to such long-term non-point sources of pollutants as the cultivation of agricultural land, acid mine drainage, and landfill seepage. Construction work can be further defined in terms of the type of project (e.g., the construction of a power plant) and by the series of construction practices required on any given project.

Among the various types of construction projects involved in the erection of the proposed coal conversion facility, the following require relatively large blocks or corridors of land, and thus pose the greatest threat to the existing air, water, and land resources at any construction site:

- Transportation networks and corridor construction (highways, roads, railroads, pipelines, and transmission lines)
- Energy facilities construction (coal conversion facilities, coal preparation and storage areas, power plants, and refineries)
- Water resource developments (major reservoirs, etc.)
- Stream channel modifications (dredging, channel relocation, etc.)
- Hazardous and special waste disposal areas (industrial process effluent and residuals).

Several categories of construction practices having the potential for appreciable short-term environmental impacts at any given construction site, are as follows:

- Temporary facilities - buildings, roads, asphalt batch plant, concrete batch plant, shops, staging areas, and stream channel relocation

- Site work - clearing and grubbing, demolition, excavation, grading, rock removal, soil stockpiles, borrow pits, landfills, drainage, paving, trenching for pipelines, and utilities and landscaping

- Construction materials and site-derived products - paint, containerized cement, solvents, petroleum products, bituminous damp-proofing compounds, pesticides, wood and metal products, and explosives

- Mechanical equipment and controls - bulldozers, earth movers, conveying systems, oil storage tanks and controls, L-P gas tanks, and wastewater treatment

- Project closeout - site restoration, demolition, preliminary start-up and testing of the facility.

The types, sources, and amounts of pollutants (air, water, and solid waste) generated at the construction site are dependent upon the type of construction project, the construction practice, and the time duration and phasing of required construction practices or activities. Other contributing factors include the following items:

- Geographical location (geology, soils, etc)

- Number of machines and workers on the site

- Size of the site, and its topography

- Rainfall distribution, volume, and frequency

- Effectiveness of measures for control of soil erosion and overland flows

- Resistance of exposed soil materials to erosion by water, wind, gravity, and ice

- Physical and chemical properties of subsurface soil materials.

3.4.3.1 Major Air Pollutants

Air pollutants occur as gases (SO_x, NO_x, CO, hydrocarbons and photochemical oxidants), odors, smoke, particulates (dust, etc.) and aerosols. The association of classes of air pollutants with the several categories of construction practices described earlier in this section may be categorized along the following lines:

TABLE 3-40. CONSTRUCTION PRACTICES AND ASSOCIATED AIR POLLUTANTS

Temporary facilities	Primary air pollutants
• Workshops	- Gases, odors, and fumes
• Access roads	- Particulates, gases
• Aggregate processing plant	- Particulates, gases
• Asphalt batch plant	- Odors, gases, and particulates
• Concrete batch plant	- Particulates (dust)
• Oil storage areas	- Fumes, odors
Site Work	**Primary air pollutants**
• Clearing, grubbing and burning	- Particulates, smoke
• Demolition	- Noise, particulates (dust)
• Site grading	- Particulates (dust)
• Excavating and blasting	- Noise, particulates (dust)
• Bituminous paving	- Odors, particulates
• Roadway excavation/grading	- Particulates (dust)

(continued)

TABLE 3-40. (continued)

Construction materials	Primary air pollutants
Solvents and coatings	Odors and fumes
Bituminous damp-proofing compounds	Odors and fumes
Mechanical equipment and controls	**Primary air pollutants**
Machines (graders, dozers, etc.)	Gases, photochemical oxidants, and noise
Fuel storage areas	Odors and fumes
Wastewater treatment	Odors
Project closeout	**Primary air pollutants**
Demolition and relocation of temporary facilities	Noise, dust
Startup and testing of the coal conversion and auxiliary facilities (may require 90 days or more)	Gases, particulates, noise

3.4.3.2 Water Pollutants and Their Transport

The major water pollutants resulting from construction activity are sediment and nutrients. Practically any water soluble element, organic pollutant, or its soluble degradation products residing in surface or subsurface soils can be transported in solution by overland runoff waters into streams and rivers, to underground aquifers by infiltration and percolation, and to drinking water in wells by seepage. Leachates from inorganic and organic waste materials also can enter surface and groundwaters. Most of the water-insoluble pollutants can be transported as films on sediment and other suspended particles, and in stormwater runoff as an emulsion or sorbed to organic debris. The metal elements such as copper, zinc, and chromium are transported to surface waters largely adsorbed within the crystalline lattice structure of sediment particles.

Chemical pollutants originating from the degradation and leaching of organic and inorganic materials (e.g., soil additives, plastic boards, paints, oils, and polymeric coatings) comprise a relatively small and little-understood source of water pollutants. The quantity of decomposition products and leachates entering surface waters from these materials is unknown at present. Some of the major organics being used in construction materials and tools include polyvinyl chloride, thermoplastic polyesters, epoxy fibers, and many others.

Organic liquid chemicals include those used for sealing cracks and for gluing materials together, the petroleum products (oils, grease, gasoline, and diesel fuels), organic fertilizers, organic pesticides, plastics, rubbers, and various curing agents.

Among this group of diverse solid and liquid materials, only the degradable materials would be of concern. The nondegradable synthetics are most often used for the fabrication of heavy-duty construction materials.

Some of the commonly used soil additives (i.e., those applied to the soil during construction in order to obtain desired soil characteristics) include lime, fly ash, asphalt, phosphoric acid, sodium chloride, and calcium chloride. The amounts of soil additives leaving a construction site have not been established, and screening methods for evaluating their effects have not been developed.

Biological pollutants include the surface soil microorganisms (bacteria, fungi, and viruses), decomposing remains of soil invertebrates (worms, insects), and organic by-products of various kinds (amino acids, sugars, etc.) in topsoil which, on entry into surface waters, act to increase the BOD, COD, and the amount of suspended solids.

The association of nonpoint source water pollutants with the various construction practices is categorized as follows:

TABLE 3-41. CONSTRUCTION PRACTICES AND ASSOCIATED NONPOINT SOURCE WATER POLLUTANTS

Temporary facilities	Primary water pollutants
• Access roads, and exposed cut and fill areas	- Sediment, petroleum products, heavy metals, deicing chemicals
• Sanitary facilities	- Microorganisms, viruses, chemicals
• Vehicular and other workshops	- Petroleum products, solvents, synthetic organics
• Aggregate processing	- Sediment, dissolved solids
• Asphalt processing	- Petroleum products, sediment
• Concrete batch plant	- Sediment, dissolved solids, heavy metals
• Unpaved parking lots	- Sediment, deicing chemicals, petroleum products
• Storage yards	- Sediment, construction chemicals spillages
• Site drainage	- Sediment, petroleum products, and chemicals

Site work	Primary water pollutants
• Clearing, grubbing, and grading	- Sediment
• Demolition	- Sediment
• Excavating and blasting	- Sediment
• Trenching for utilities, etc.	- Sediment
• Roadway excavating and grading	- Sediment

(continued)

TABLE 3-41. (continued)

Site work (continued)	Primary water pollutants
• Soil treatment	- Nutrients, heavy metals, sediment
• Site drainage, stream channel relocation, and dredging	- Sediment, microorganisms, heavy metals
Project closeout	**Primary water pollutants**
• Site restoration, finish grading, topsoiling, fertilizing, and revegetation	- Sediment, nutrients, and pesticides
• Startup and testing of the coal conversion and auxiliary facilities (may require about 90 days)	- Inorganics, oils, nutrients, organics
• Revegetation/landscaping	- Nutrients, pesticides
Construction materials	**Primary water pollutants**
• Portland cement	- Suspended solids, heavy metals
• Wood preservatives	- Solvents, pentachlorophenol
• Special coatings and solvents for oils and paints	- Bituminous and other organics
Mechanical equipment	**Primary water pollutants**
• Machines (graders, dozers, etc.)	- Oils, greases, and heavy metals
• Fuel spills	- Petroleum products, heavy metals
• Wastewater treatment	- Water treatment chemicals, coagulants, clarifiers, etc.

3.4.3.3 Solid Wastes

The major construction-related solid wastes include all of the wood, metal, organic, polymeric, and mineral materials used in the construction process. Also included under this category are the paper and cardboard products derived from wood; solid wastes from sanitary facilities; rock; slash and tree stumps; wastewater sludge; and sludge from concrete and aggregated processing plants; all solid wastes from demolition operations; and materials dredged from streams, rivers, and lakes.

The association of the several solid wastes with the various construction practices is categorized as follows:

TABLE 3-42. CONSTRUCTION PRACTICES AND ASSOCIATED SOLID WASTES

Temporary facilities	Primary solid wastes
• Workshops and field offices	- Paper, wood, abandoned furnishings, waste glass, plastics, rubber
• Sanitary/wastewater treatment	- Paper, sludge
• Aggregate, concrete and asphalt processing plants	- Stone, cement, asphalt, bituminous materials
Site work	Primary solid wastes
• Clearing	- Tree slash and stumps
• Demolition	- Wood, metal, brick
• Excavation/blasting	- Rock and stone
• Roadway excavation	- Rocks, soil stockpile
• Dredging	- Dredged material solids
Construction materials and site-derived products	Primary solid wastes
• Building and heavy construction	- Metals, plastics, aggregate, lumber, plaster, lath, terrazzo
• Site-derived products for resale or recycling	- Lumber, brick, fence posts, stone, wood chips, rock, timber, minerals
• Packaging materials	

(continued)

TABLE 3-42. (continued)

Equipment and mechanical controls	Primary solid wastes
● Wastewater treatment	- Sludge, grease
● Heavy machinery	- Oil, grease
● Incinerators/ash removal	- Ash
● Pulping/chipping machines	- Paper, wood chip
Project closeout	**Primary solid wastes**
● Demolition	- Lumber, concrete, metal, aggregate, sludges
● Start-up and testing of the plant and auxiliary facilities	- Fly ash, ash, and sludges

3.4.4 Environmental Protection During Construction of the SRC Plant

The characteristics of a given site (abiotic and biotic) are crucial to the development of comprehensive environmental protection plans for that site. Therefore, a general discussion will be given to this question, in view of the fact that a specific SRC site has not been selected.

The realization of sound environmental protection strategies during construction of the SRC plant requires the use of preliminary site evaluations; subsurface explorations; and nominal baseline inventories as a prelude to the development of site-specific sediment, air, and other pollutant control plans. Once these plans have been reviewed and approved by delegated authority, they should become an integral part of the construction contract specifications. In this approach, prospective contractors may bid and plan more intelligently for any given construction site.

The nature and extent of potential environmental changes resulting from construction work, whether of a beneficial or adverse nature, can be influenced materially by the scope of the protective measures specified in the construction contract. For example, in the 17 or more states in which specific erosion and sediment control laws have been adopted, the construction permit will not be issued until an erosion and sediment control plan, specific to the jobsite, has been approved. The State of Illinois presently has no specific statutory requirements for the control of sediment on construction sites.

Aside from meeting the requirements of sediment control statutes, constructors must be aware of federal, state, and local requirements for the monitoring of sediment and other pollutant discharges, the protection of fish and wildlife values, air quality, recreational and aesthetic values in streams and waterways, noise, solid waste disposal, spills of hazardous substances, and the safe handling and storage of hazardous chemicals. These and other potential pollutants resulting from construction activity were identified earlier in this section. The contractor should be required to submit his preliminary plans for mitigating impacts at least 30 days before starting any land-disturbing work on the jobsite.

During the construction phase, the contractor should furnish all materials, labor, and equipment required to protect and monitor the environment, as called for in plans for erosion and sediment control, stormwater runoff control, dust control, solid waste disposal, and controlling spillage and disposal of petroleum and other hazardous products. Selected items of work considered relevant to environmental protection at the construction site are shown in Table 3-43.

TABLE 3-48. SELECTED ENVIRONMENTAL PROTECTION MEASURES ON CONSTRUCTION SITES (42,44,45)

General Landscape	Fish and Wildlife	Dust Control	Temporary Soil Erosion and Sediment Control	Permanent Soil Erosion and Sediment Control	Environmental Monitoring
Stream crossing areas	Dentree protection	Unpaved access and haul roads	Sediment traps	Sediment basins	Baseline monitoring of air, water, and land.
Tree protection	Streambank protection	Demolition of buildings	Straw bales	Detention basins	Trend monitoring for air, water, and land.
Tree relocation	Fish ladder installation, if necessary	Borrow pit area	Straw/hay mulches	Stone riprap on streams banks	Discharge (NPDES) monitoring for air, water and land.
Road relocation	Nesting/breeding box installation, if necessary	Concrete batch plant area	Gravel inlet filters	Gabions	Control monitoring for air, water, and solid wastes.
Removal of loose rock		Asphalt batch plant area	Diversion ditches, terraces, and dikes	Drainageway linings	Legal standards monitoring for water, air, and leachate
Fence installation			Serrated slope areas	Grade stabilization structures	
			Interceptor dikes	Revetments for shoreline and erosion control	
			Flexible downdrains		
			Flumes		
			Level spreaders		
			Chemical soil stabilizers		
			Stone and gravel mulch		
			Slope retention structures		

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4.0 ENVIRONMENTAL DATA, WHITE COUNTY, ILLINOIS

4.1 Summary of Environmental Issues

Southern Illinois, Indiana, and western Kentucky, while prominent in agricultural pursuits, nevertheless have a strong orientation toward the extractive industries. Indeed, a recent report has suggested that the Eastern Interior coal reserve region would be expected to augment this orientation with excellent transportation facilities, and a future land use emphasis on intensive industrial development (1). The length of time required to build and operate a coal conversion facility is shown in Figure 4-1, assuming no delays from shortages of various kinds or other delays arising from changing regulatory constraints on air, water, and hazardous waste pollutants. If the 1985 goals for clean energy are to be met, it is evident that firm commitments to build and operate synfuel plants would be required no later than 1979 (2).

Recent findings of the Argonne National Laboratory Regional Studies program (ANLRS) indicated significant constraints to the siting of synfuel plants in the 14-state midwest region (3). Thus, the ANLRS study reported that only five of the 14 states in the region (Illinois, Indiana, Missouri, North Dakota, and Ohio) exhibited a suitable coincidence of usable water and coal resources (3). One scenario relevant to synfuels development is the accelerated synfuels scenario. Based on this scenario, there could be six coal liquefaction plants in North Dakota, one in Missouri, five in Illinois, two in Indiana, and two in Ohio by the year 2020 (3).

Generic environmental issues pertaining to the siting, construction, and operation of synfuel plants are summarized

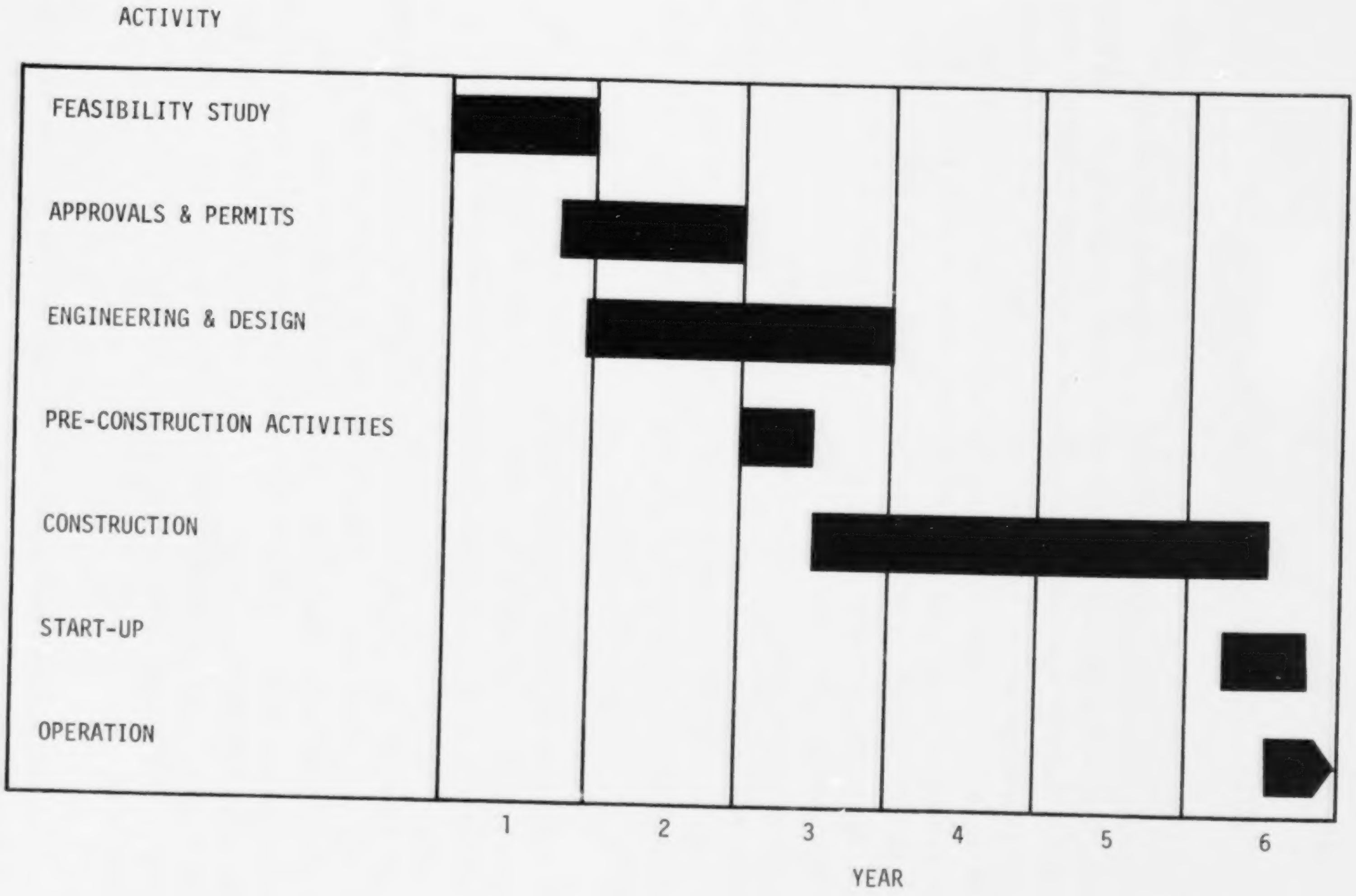


Figure 4-1. Project schedule for building coal conversion facility (2)

in the next two subsections. Environmental issues specific to White County, Illinois, are discussed later in this chapter.

4.1.1 Issues Relating to the Siting and Construction of SRC Plants

The following site-related issues are considered of major importance to the future location of synfuel plants in the coal-producing regions:

- Adequate mineable coal reserves, coincident with abundant water supplies for the 25-year life of the SRC plant
- Limitations on siting imposed by the Federal Prevention of Significant Air Deterioration regulations and the Clean Water Act
- Water allocation conflicts between existing industrial/utility plants, and future synfuels plants (e.g., consumptive in-stream uses)
- Transportation constraints linked to the possible accelerated abandonment of railroads and of highways due to mounting maintenance and construction costs
- Potential risks from natural disasters (e.g., earthquakes and tornadoes) and the costs of structural engineering countermeasures
- Adequacy of the 7-day/10-year low flows in meeting the water requirements during the 25-year life of

the SRC facility, in relation to the sequential siting of industries and utilities

- Constraints arising from the prime farmland concept of the U.S. Department of Agriculture, in relation to the land requirements for new roads, pipelines, and transmission lines
- Adverse socioeconomic and growth impacts in rural areas and on small towns
- Adverse impacts on historic landmarks, centennial farms, historic trails, and archeological sites
- Potential for disruption of aquifers as a result of coal extraction
- Potential for disruption of the non-consumptive, in-stream uses of surface water (e.g., hydroelectric power generation, fish and wildlife maintenance, navigation, recreational uses, and water quality control)
- Effects of the offset principle on SRC siting in Class I areas, relative to existing or projected gaseous emissions from sources other than SRC
- Regulatory constraints on flood plain development
- Federal coal-leasing policy
- Prohibitions on water withdrawal (e.g., Indiana law prohibits withdrawal when the Wabash River discharge at Riverton, Indiana, reaches 120 percent

of the 7-day consecutive minimum average flow with a recurrence interval of 10 years)

- Constraints to new mine development posed by oil well regulations
- Water pumping costs.

4.1.2 Issues Relating to the Operation of SRC Plants

Generally, the following environmental issues would be identified with the operation of the SRC plant and auxiliary facilities:

- Potential for negative impacts on plants, animals and man, of air pollutants and leachates from coal preparation and cleaning
- Potential for negative impacts from leachates and effluents from sludge, fly ash, and bottom ash ponds on groundwater resources
- Potential effects on climatic patterns as a result of the emission of CO_2, CO, water vapor, and heat
- Negative effects of trace elements, heavy metals, and nutrients contained in sediment, leachate, and surface runoff from coal stockpiles and hazardous waste disposal sites on surface and groundwater resources
- Occupational health hazards for workers
- Radionuclide release from burning low-sulfur Western coal supplies

- Potential for disruption of aquifers resulting from increased rates of pumping of water and extraction of coal.

4.2 Characterization of Abiotic Features of White County

The primary objective of this section is to provide detailed characterization information relating specifically to White County, Illinois. Such information will be utilized to estimate ways in which the construction and operation of a coal liquefaction facility would impact a specific site.

4.2.1 Water Resources

4.2.1.1 Surface Waters

White County is bounded on the east by the Wabash River and is drained internally by the Little Wabash River. As shown in Figures 4-2 and 4-3, most of White County is located in the Wabash River Drainage Basin. A 5 to 11 km strip along the eastern border of the county is part of the Lower Wabash Sub-basin and drains directly into the Wabash River (5). The Little Wabash River and tributaries which drain the major portion of the county are part of the Little Wabash Sub-basin. In contrast, the southwest corner of the county is located in the Ohio Drainage Basin and drains into the Ohio rather than the Wabash River.

The Wabash River is one of the largest tributaries of the Ohio River and together with its major tributaries (Salamonie, Mississinewa, White, Embarras, Little Wabash, and Patoka Rivers), drains an area of 85,729 km^2. The Wabash River drainage area includes about two-thirds of Indiana, one-sixth of Illinois, and about 826 km^2 of Ohio in its 764 km of length. The river serves as a common boundary

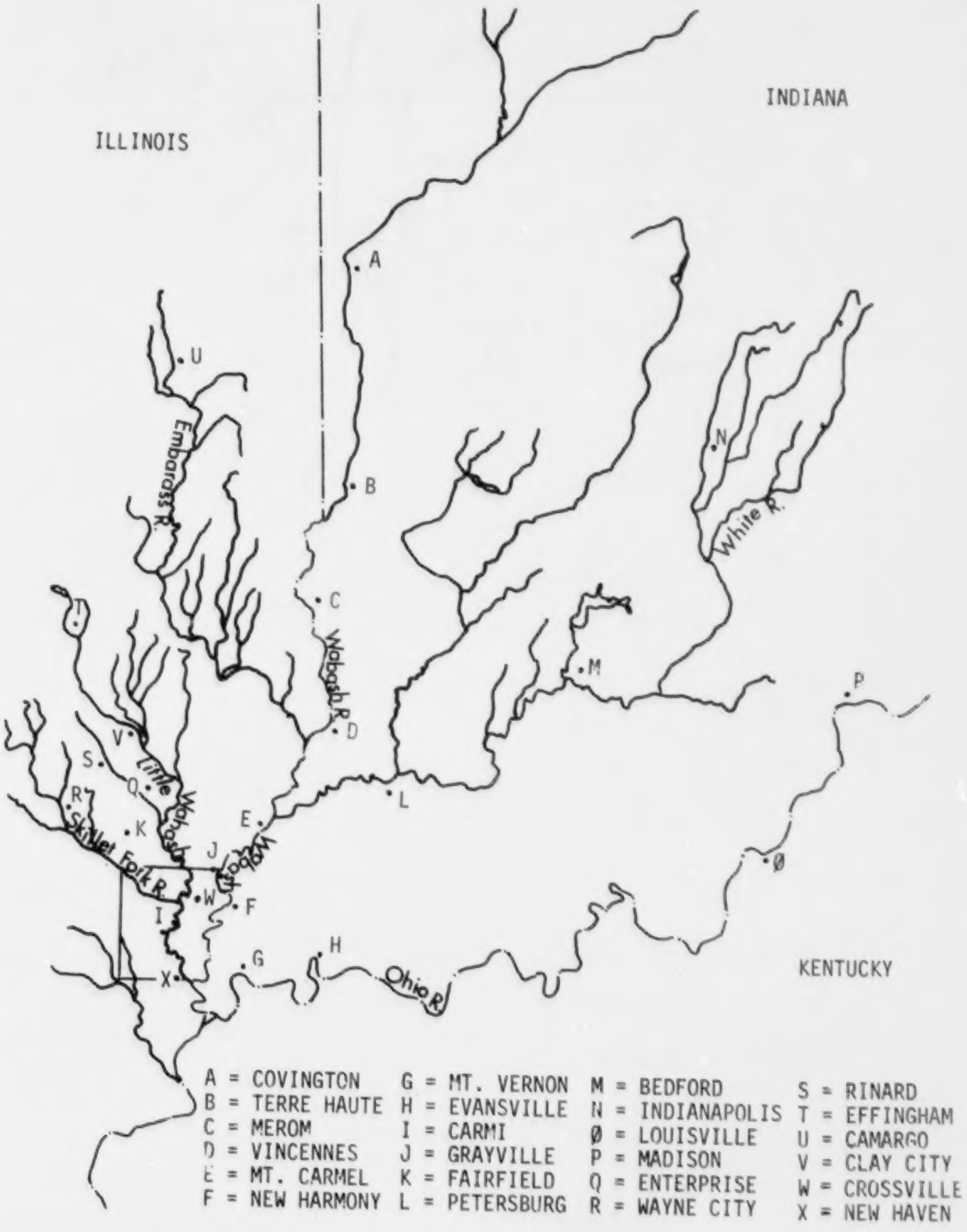
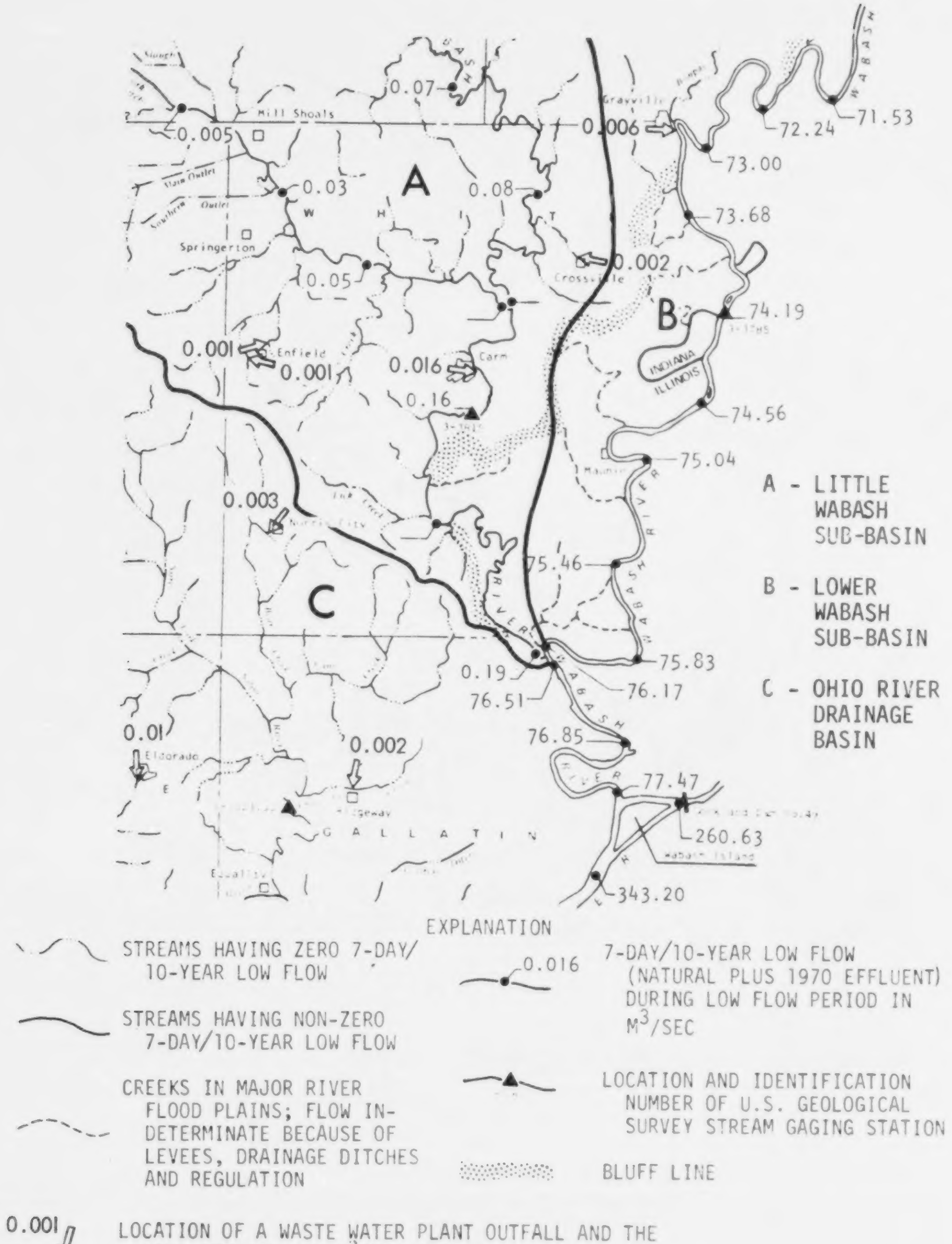

ILLINOIS
INDIANA
KENTUCKY
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
U
V
W
X
Embarrass R.
Wabash R.
White R.
Little Wabash
Skillet Fork R.
Wabash
Ohio R.
A = COVINGTON
B = TERRE HAUTE
C = MEROM
D = VINCENNES
E = MT. CARMEL
F = NEW HARMONY
G = MT. VERNON
H = EVANSVILLE
I = CARMI
J = GRAYVILLE
K = FAIRFIELD
L = PETERSBURG
M = BEDFORD
N = INDIANAPOLIS
O = LOUISVILLE
P = MADISON
Q = ENTERPRISE
R = WAYNE CITY
S = RINARD
T = EFFINGHAM
U = CAMARGO
V = CLAY CITY
W = CROSSVILLE
X = NEW HAVEN

Figure 4-2. Wabash River sub-basin of the Ohio River drainage system



0.07
0.005
Hill Shoals
0.006
72.24
71.53
73.00
A
0.03
0.08
73.68
Springerton
0.002
Crossville
0.05
B
74.19
0.001
Enfield
0.001
0.016
Carmi
INDIANA
ILLINOIS
0.16
74.56
75.04
A - LITTLE WABASH SUB-BASIN
B - LOWER WABASH SUB-BASIN
C - OHIO RIVER DRAINAGE BASIN
0.003
Norris City
75.46
WABASH RIVER
C
75.83
0.19
76.51
76.17
0.01
Eldorado
0.002
76.85
77.47
Ridgway
GALLATIN
260.63
Wabash Island
Equality
343.20
EXPLANATION
STREAMS HAVING ZERO 7-DAY/10-YEAR LOW FLOW
STREAMS HAVING NON-ZERO 7-DAY/10-YEAR LOW FLOW
CREEKS IN MAJOR RIVER FLOOD PLAINS; FLOW INDETERMINATE BECAUSE OF LEVEES, DRAINAGE DITCHES AND REGULATION
0.016
7-DAY/10-YEAR LOW FLOW (NATURAL PLUS 1970 EFFLUENT) DURING LOW FLOW PERIOD IN M3/SEC
LOCATION AND IDENTIFICATION NUMBER OF U.S. GEOLOGICAL SURVEY STREAM GAGING STATION
BLUFF LINE
0.001
LOCATION OF A WASTE WATER PLANT OUTFALL AND THE 1970 EFFLUENT IN M3/SEC DURING A 7-DAY LOW FLOW PERIOD

Figure 4-3. White County drainage (4)

between Illinois and Indiana for approximately 322 km before joining the Ohio River 10 miles south of White County and 214 km above the confluence of the Ohio and Mississippi Rivers (4,6).

A large part of the Lower Wabash Sub-basin is level flood plain, cut by sloughs and oxbow bends near the major streams. In these flat areas the river gradient ranges as low as 0.15 m per 1.61 km, compared to an average drop of about a 0.30 m per 1.61 km over the entire length of the Wabash (6).

Because of limited depth, there is no navigation on the Wabash River except for ferries and sand and gravel dredging operations (6). In some cases, river depths are reported up to 12 m, although 7.6 m will probably be the maximum depth at most of the deeper holes. The average depth of the river is about 3 m (7).

Stream flow characteristics for rivers in the vicinity of White County are shown in Table 4-1 and Figure 4-3. The Wabash River at Grayville has an average river flow of 740.6 m^3/sec, with maximum and minimum flows of 12,330 and 46.8 m^3/sec. In common with other central U.S. rivers, the Wabash River has major fluctuations in flow throughout the year. Yearly peak flows on the Wabash commonly occur in late winter and spring. Low flows can be expected to occur in September or October. Flow fluctuations are such that maximum daily discharge may be over 20 times greater than the minimum daily flow (6).

The volume of stream flow is of primary significance in assessing the potential environmental impact of a coal liquefaction facility in terms of effluent dilution rate, net percentage loss of river volume, and temperature

TABLE 4-1. STREAM FLOW FOR RIVERS IN WHITE COUNTY VICINITY (4,5)

					(m^3/sec)		
	Kilometers Above Mouth	Location	Drainage Area km^2	7-day 10-year Low Flow	Average Flow	Maximum Flow	Minimum Flow
Wabash River (Above Ohio River)	151	Mt. Carmel, IL	74,000	70.5	734.5	12,120	46.8
	105	Grayville, IL	74,100	73.0	740.6	12,330	46.8
	83	New Harmony, IN	75,524	74.2			
	20	New Haven, IL (above Little Wabash River)		76.2			
	21	New Haven, IL (below Little Wabash River)		76.5			
	0	Before confluence with Ohio River		77.5			
Ohio River (above Mississippi River)	454	Evansville, IN	277,130	246.6	3,792	39,927	N.D.
	230	Just east of confluence with Wabash River		260.6			
	203	Just south of confluence with Wabash River		343.2			
Little Wabash River (above Wabash River)	48	Carmel, IL	8,058	0.16	69	1,328	0.02
		Before confluence with Wabash River		0.19			

increase of river. Mean flow volumes provide helpful information, but the minimum flow values are more pertinent for providing data for the "worst case" situation with regard to environmental impact. The 7-day/10-year low flow values have a further significance in that regulations regarding the Wabash River frequently utilize those flow rates. These values are the lowest average flow rates that occur for a consecutive 7-day period at a recurrence interval of 10 years. That is, over a long period of years, the average time interval between 7-day low flows of this severity will be 10 years.

Daily water requirements of coal conversion plants have been estimated to range from 23,000 to 270,000 m^3. The water loss will vary with the type of conversion process (coal liquefaction requiring less than gasification) and with the extent to which water conservation methods are utilized. In this report, the lower value of 23,000 m^3/day was used as the estimated consumptive water usage per day. A loss of 23,000 m^3/day represents 0.3 percent of the 7-day/10-year low flow volume of the Wabash River at Grayville, Illinois. The stream flow volume of the Little Wabash River (7-day/10-year low flow at Carmi is 13,800 m^3/day) is obviously insufficient to support a coal conversion facility.

High flows are generally addressed in terms of flood impact and are of particular concern in White County. Between one-third and one-half of the county is categorized as a flood-prone area in terms of the inundation probability during 100-year flood levels. In general, the area located east of the bluff line shown in Figure 4-3 is subject to flooding, as well as land adjacent to the Little Wabash River and Skillet Fork Creek.

4.2.1.2 Groundwater

Specifying that the location of the coal liquefaction facility would be along the Wabash River implies that surface water would be utilized as the water source for the facility. However, an examination of the groundwater supply is valuable in assessing the following: (1) the conditions that make groundwater the most desirable water source for a coal conversion facility, and (2) the effect of an SRC facility on the groundwater resources.

The quantity of water needed for coal conversion plants lies between 23,000 m^3/day and 270,000 m^3/day. In terms of groundwater development, this is a vast supply. Therefore, from a groundwater viewpoint, only those locations where groundwater conditions are especially favorable can be considered as possible SRC sites. In Illinois favorable conditions exist in areas where yields of wells are high (in excess of 2 m^3/min), where the aquifers are extensive and highly permeable, and where either the natural rate of recharge is high or water can be induced (by pumping of nearby wells) to flow from the streams into the groundwater reservoir, a process called induced infiltration (8).

Groundwater in Illinois is commonly drawn from unconsolidated deposits of sand and gravel in the glacial drift or in river valleys, or from bedrock formations of limestone or sandstone. Most of the unconsolidated, or sand and gravel, aquifers of Illinois were deposited by meltwater from glaciers. The sand and gravel were deposited mainly in valleys leading away from the melting ice or in outwash plains at the front of the ice. Of the areas in Illinois where conditions are favorable for drilling wells yielding 2 m^3/min, most lie within major valley systems. As seen in Figure 4-4, the present-day Wabash River overlies major sand

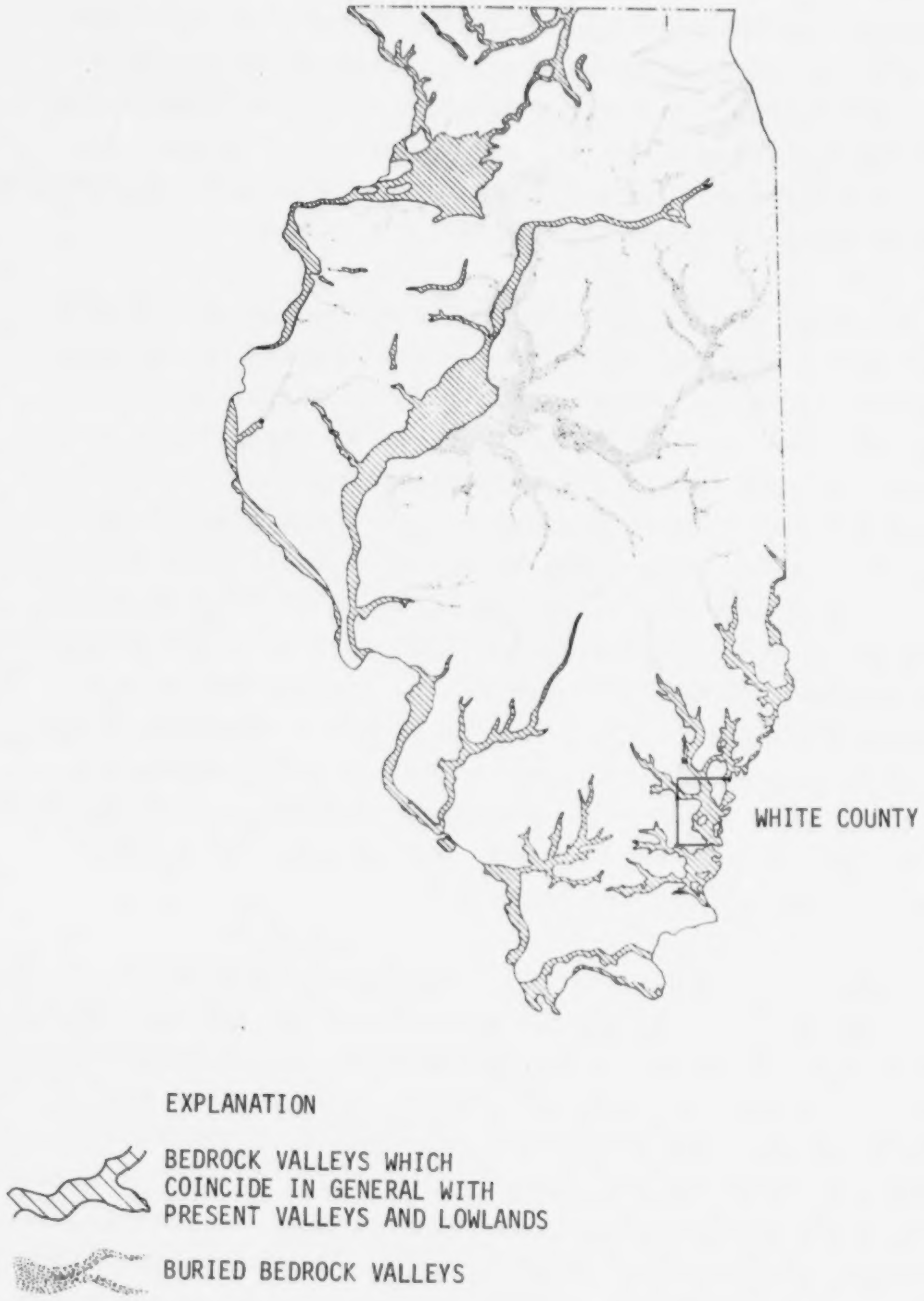

WHITE COUNTY
EXPLANATION
BEDROCK VALLEYS WHICH COINCIDE IN GENERAL WITH PRESENT VALLEYS AND LOWLANDS
BURIED BEDROCK VALLEYS

Figure 4-4. Distribution of glacial aquifers in major bedrock valleys (9)

and gravel aquifers of the ancestral Wabash Valley. The aquifers extend from Mount Carmel, Illinois to the Ohio River (including the eastern section of White County) and store an estimated 1.4 x 10^9 cubic meters of water. A mantle of permeable material covers the aquifers, allowing a recharge rate of approximately 300,000 m^3/day.

Although essentially undeveloped, the potential well yield from the Wabash Valley aquifers (including eastern White County) is in excess of 2 m^3/min, the minimum yield acceptable for developing groundwater as the primary water source for coal liquefaction plants. The most productive sections of the aquifers underlie the flood plain areas, with well yields decreasing with distance from the Wabash River (see Figure 4-5). The portions of White County not overlying the Wabash River Valley aquifer draw groundwater from sandstone and limestone beds of Pennsylvanian and Mississippian age. These bedrock aquifers commonly yield less than 0.1 m^3/min; far below the 2 m^3/min. estimated required rate for a coal conversion facility. Such aquifers are of little interest in terms of the need for a major water source for process operations.

The proposed plant site, southwest of Grayville, is located above the flood plains and beyond the extremities of the Wabash Valley aquifer. Groundwater, after being pumped from this high-yield aquifer, would, like surface water, have to be transported several kilometers to the facility. Therefore, although the groundwater yields along the Wabash River are considered adequate to support a coal liquefaction facility, the availability of adequate surface water lessens the possibility of groundwater being utilized as the major water supply. Under certain conditions, however, groundwater use may be the most desirable alternative. For example, if surface water quality is inadequate for process

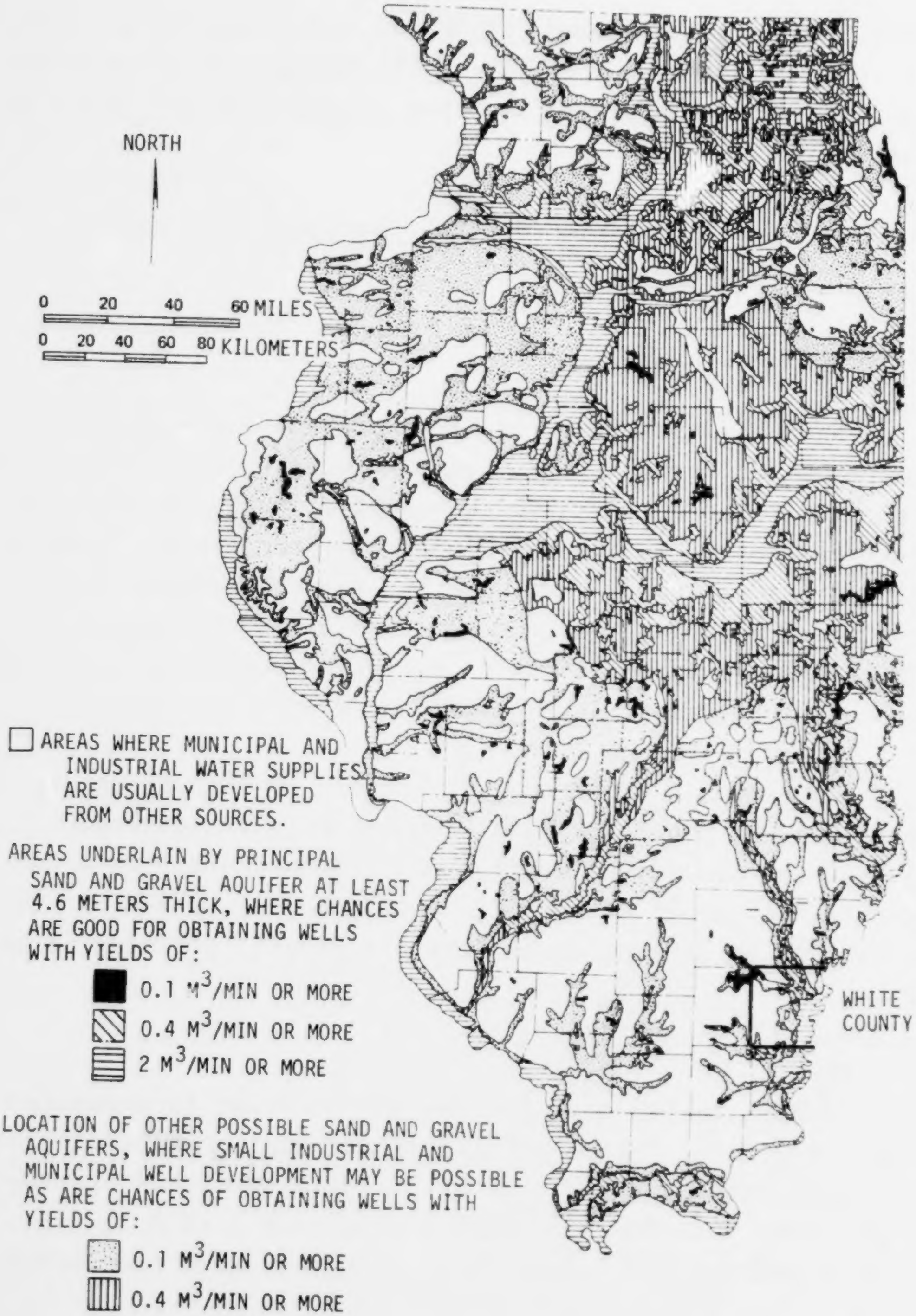

NORTH
0 20 40 60 MILES
0 20 40 60 80 KILOMETERS
AREAS WHERE MUNICIPAL AND INDUSTRIAL WATER SUPPLIES ARE USUALLY DEVELOPED FROM OTHER SOURCES.
AREAS UNDERLAIN BY PRINCIPAL SAND AND GRAVEL AQUIFER AT LEAST 4.6 METERS THICK, WHERE CHANCES ARE GOOD FOR OBTAINING WELLS WITH YIELDS OF:
0.1 M3/MIN OR MORE
0.4 M3/MIN OR MORE
2 M3/MIN OR MORE
LOCATION OF OTHER POSSIBLE SAND AND GRAVEL AQUIFERS, WHERE SMALL INDUSTRIAL AND MUNICIPAL WELL DEVELOPMENT MAY BE POSSIBLE AS ARE CHANCES OF OBTAINING WELLS WITH YIELDS OF:
0.1 M3/MIN OR MORE
0.4 M3/MIN OR MORE
WHITE COUNTY

Figure 4-5. Yields of sand and gravel aquifers (8)

needs, or if river water withdrawal is restricted by regulations, as when river volume falls below 120% x 7-day/10-year low flow = 87.6 m^3/sec, then groundwater use would be desirable.

4.2.2 Existing Water Quality (Background Levels of Stressors)

4.2.2.1 Introduction

When a water supply is being planned for a particular use, such as for a coal conversion facility, it is important to establish the amount and kinds of minerals in the water in order to estimate the cost of water treatment. However, no general standards have been set for the minimum water quality required by various coal conversion processes. Therefore, water quality will not be discussed in terms of process requirements and required raw water treatment.

The primary water quality concern of this report is the potential of the coal conversion facility to adversely affect the quality of surface and groundwaters. In order to assess the impact of a facility on the area waters, it is essential to determine the baseline quality of those waters.

4.2.2.2 Surface Water

Water quality data for the Wabash River is presented in Table 4-2. The Wabash normally shows high pH levels, occasionally exceeding the Ohio River Valley Water Sanitation Commission (ORSANCO) criteria limits of 6.0 to 8.5. The yearly average in 1977 was 8.2, with a maximum single value of 8.9 (10).

TABLE 4-2. WATER QUALITY - WABASH RIVER AT NEW HARMONY, INDIANA

(Concentrations in mg/l unless stated otherwise) (10)

Parameter		Oct. 1975 - June 1976				Jan. 1977 - Dec. 1977					
		Number of Months Sampled	Arith. Mean	Min	Max	Number of Samples	Arith. Mean	Geom. Mean	Min	Max	S.D.
Ammonia	NH_3	8	0.08	0.01	0.15	33	<0.18[c]	<0.11	<0.05	0.89	0.2
Arsenic	As	1	0.002	-	-	4	<0.01		<0.01	<0.01	
Barium	Ba	3	0.08	0	0.2	11	<0.2		<0.2	<0.2	
Cadmium	Cd	5	<0.001	0	0.002	11	<0.005		<0.005	<0.005	
Calcium	Ca	8	65	42	127	32	65	63	32	102	15.5
Cyanide		7	0.00	0.00	0.00	32	<0.01		<0.01	<0.01	
Chloride	Cl	6	23	15	30						
Chromium	Cr	5	<0.01	<0.01	<0.01	11	<0.03		<0.03	<0.03	
Copper	Cu	4	0.008	0.004	0.01	11	<0.03		<0.03	<0.03	
Carbon - Total Organic		4	10	5.7	14						
Fluoride	F	6	0.5	0.2	0.9						
Iron	Fe	5	1.8	0.01	3.9	11	3.36	1.54	0.24	10.9	3.8
Lead	Pb	5	0.04	0.009	0.11	11	16	12	<5	46	13
Magnesium	Mg	7	21	12	26	32	23	22	9	35	6.6
Manganese	Mn	5	0.15	0.1	0.21	11	0.27	0.23	0.13	0.82	0.20
Mercury	Hg	5	<0.0005	-	<0.0005		<0.0005				
Nickel	Ni	3	0.012	0.011	0.013	11	<0.1		<0.1	<0.1	
Nitrate	NO_3	7	2.4	1.3	3.2	33	<1.7[c]	<1.1	<0.05	3.74	1.1
Nitrogen (TKN)		8	1.1	0.8	1.5	33	1.1	.94	0.3	4.9	0.8
Phenol		8	0.001	0	0.002	33	<2[c]	<4	<2	35	9.2
Phosphorus - Total		8	0.20	0.09	0.35	33	<0.34[c]	<0.24	<0.05	1.19	0.29
Potassium	K	6	2.8	2.3	3.4						
Selenium	Se	1	0.001	-	-	4	<0.005		<0.005	<0.005	
Silicon dioxide	SiO_2	4	5.2	2.8	8.3						
Silver	Ag	3	0	0	0	4	<0.03		<0.03	<0.03	
Sodium	Na	7	15	6.7	21	14	24.5	22	10	43	11.1
Sulfate	SO_4	8	65	35	85	33	77	75	40	112	19
Zinc	Zn	5	0.03	0.02	0.05	11	<32[c]	<35	<30	90	18
Alkalinity		6	168	106	201						
BOD_5		4	3.9	2.2	7.5	10	5.2	4.5	1.7	11	3.0
Coliform-fecal[a]		7	223	100	440	12	966	235	10	9,400	2,004
Coliform - total		7	11,200	300	60,400	31	5,210	0	0	33,000	7,630
Hardness - total		8	245	150	290						
Solids - suspended		8	101	32	296	33	112	64	2	560	119
Solids - dissolved		8	324	209	385						
pH[b]		12	8.2	6.9	8.9	31	8.0	8.0	7.1	8.9	0.4
Dissolved Oxygen[b]		12	9.2	4.4	16	33	10.0	9.5	5.3	17.5	3.2
Cond.						33	524	512	345	780	117
Temp.						33	14.6	0	0	30.5	10

[a] Count/100 ml

[b] 1977 samples

[c] For calculation purposes, values of 0.05, 2, 5, 10, 30 are considered to be 0.05, 2, 5, 10 and 30, respectively.

The water quality in the Wabash River fluctuates significantly depending on the flow (11). The high flows associated with rapid overland flow from farmlands contribute suspended sediment and dissolved solids to the river. During high-flow periods, specific conductance and total solids concentrations are high. Suspended sediment loads are also high, but tend to drop as flows recede. Variation in temperature affects the dissolved oxygen content. In general, a rising water temperature results in a decrease in dissolved oxygen.

During the past 20 years, certain water quality parameters have deteriorated in the Wabash River. As shown in Table 4-3, there has been a significant increase in chloride and nitrate content.

TABLE 4-3. COMPARISON OF WATER QUALITY DATA FOR PERIODS 1955-1971* (12)

	Total Dissolved Minerals		Hardness		Chloride		Sulfate		Nitrate		Turbidity	
	Median	High	Median	High	Median	High	Median	High	Median	High	Median	High
Wabash River at Hutsonville												
1966-1971	373	489	284	372	25	440	79	116	17.9	90.8	78	758
1962-1966	363	519	274	388	28	46	85	118	10.8	54.4	83	890
1955-1961	341	492	264	372	23	34	76	116	12.9	51.5	82	656

*Mineral constituents in milligrams per liter, turbidity in Jackson turbidity units.

4.2.2.3 Groundwater

Water from unconsolidated Wabash Valley aquifers generally have dissolved solids of less than 500 mg/l and a hardness of less than 400 mg/l. The New Haven municipal supply, near the mouth of the Little Wabash, has dissolved solids of 335 mg/l and a hardness of 309 mg/l (13). Analysis of water from a residential well in New Haven is given in Table 4-4.

Water from sandstone aquifers is typically of calcium bicarbonate type with a dissolved solids content of less than 500 mg/l. At depths greater than 60 meters, the water

TABLE 4-4. WATER QUALITY DATA - WELL NEAR NEW HAVEN (8)

	Concentration in mg/l
Dissolved solids	510
Hardness	342
Alkalinity	363
Iron	1.0
Manganese	0.2
Chloride	54.8
Fluoride	0.2
Nitrates	1.4
Sulfates	9.8
Temperature	59.3

from the sandstone is more likely to be of the sodium bicarbonate type with excessive dissolved solids, excessive fluorides, and in places, excessive chlorides. In general, the quality of groundwater in the Little Wabash Basin (primary bedrock aquifers) is characterized by moderate mineralization, excessive hardness, and above-normal iron content. A comparison of groundwater quality of aquifers in unconsolidated material with that from bedrock aquifers is shown in Table 4-5.

TABLE 4-5. GROUNDWATER QUALITY - WABASH BASIN (14)

	Unconsolidated sediments	Bedrock formations
	Outwash and valley train deposits along Lower Wabash (Terre Haute to mouth)	Sandstone of the Pennsylvanian system (Eastern Interior region)
Well depth (meters)	10–40	15–270
Depth of water (meters)	1–10	-
Hardness (mg/l)	250–400	50–450
Sulfate (mg/l)	25–75	25–240
Chloride (mg/l)	1–17	5–75
Total dissolved solids (mg/l)	220–450	200–2100

4.2.3 Existing Air Quality (Background Levels of Stressors)

The data presented in this section relate to the ambient air quality. Unfortunately, most of these data were gathered from facilities near urban areas and may not accurately reflect values which would be expected in ambient rural atmospheres. These data only deal with total suspended particulates, sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone. No monitoring data were found for the ambient levels of other organic or inorganic air pollutants.

White County is in Air Quality Control Region No. 74. In this region there are four reporting stations. One is at Effingham, which is approximately 120 km on a direct line NW of Carmi. Others are at Mt. Vernon (70 km WNW of Carmi), Carbondale (105 km SW of Carmi), and Marion (80 km SW of Carmi). These stations have reported a geometric mean of 50 to 59 micrograms suspended particles per cubic meter (standard geometric deviation 1.45 to 1.49), an arithmetic mean of 7.90 to 34.0 $\mu g/m^3$ (at 25°C and 760 mm Hg) sulfur dioxide, an arithmetic mean of 18.8 to 30.0 $\mu g/m^3$ (at 25°C and 760 mm Hg) nitrogen dioxide, and maximum monthly ozone levels ranging from 47.1 to 230 $\mu g/m^3$ (at 25°C and 760 mm Hg). Metropolis, which is 120 km SSW of Carmi, reported an annual average of 53 micrograms per cubic meter suspended particles in 1975 (15).

Table 4-6 summarizes information received from the Communication Manager of the Ambient Air Quality Monitoring Section, Division of Air Pollution Control, Illinois Environmental Protection Agency. These data were gathered from January to November 1977, and represent the latest available data on these pollutants in this region.

TABLE 4-6. SUMMARY OF JANUARY TO NOVEMBER 1977
MONTHLY AIR QUALITY REPORTS FOR AIR QUALITY CONTROL REGION 74
(SOUTHEASTERN ILLINOIS)[a]

Pollutant	Location	n[b]	Arith. mean	Geom. mean	Unbiased std. dev.	Range
Sulfur dioxide[c]	Effingham	43	13	8	13	5-73
	Marion	48	13	8	18	5-120
	Carbondale	30	24	16	21	5-86
Nitrogen dioxide[c]	Effingham	46	26	24	13	9-75
	Marion	50	28	0	11	0-56
	Carbondale	29	30	30	9	15-45
Suspended particulates[c]	Effingham	35	64	57	34	21-158
	Marion	47	68	57	39	3-196
	Carbondale	31	86	79	43	41-251
	Mt. Vernon	46	70	62	35	19-179

[a] This table was calculated from information provided by the Manager of the Ambient Air Quality Monitoring Section; Division of Air Pollution Control, Illinois Environmental Protection Agency, 2200 Churchill Road, Springfield, IL 62706.

[b] n = number of samples.

[c] Units are $\mu g/m^3$ at 25°C and 760 mm Hg.

The 1976 data from Air Quality Control Region 77 is summarized in Table 4-7. This region is in southwestern Indiana and contains Evansville and Jasper. Information on Terre Haute and Vincennes is also included. Evansville is approximately 50 km SE of Grayville and is approximately 30 to 50 km from the nearest point of White County. Jasper is approximately 94 km ENE of Grayville, which is the nearest point to Jasper in White County. Terre Haute is approximately 140 km NNE of Grayville, which is the nearest point in White County to Terre Haute. Vincennes is approximately

TABLE 4-7. AIR QUALITY DATA FROM LOCATIONS IN INDIANA WITHIN 140 KM OF WHITE COUNTY, ILLINOIS (MICROGRAMS PER CUBIC METER) (16)

		Total Suspended Particulates				Sulfur Dioxide				Nitrogen Dioxide			
City	Site	N*	Geometric Mean	1st Max†	2nd Max††	N*	Arithmetic Mean	1st Max†	2nd Max††	N*	Arithmetic Mean	1st Max†	2nd Max††
Evansville	1	41	57	138	101	37	22	77	72	39	26	51	48
	2												
	3	48	64	132	116								
	4	36	92	186	178	37	25	101	70				
	5	58	62	140	129	46	28	129	118	37	29	79	48
	6	54	65	159	154								
	7	14	**	141	110	14	**	66	47	15	**	97	73
	8					2802	**	453**					
	9	50	56	122	108								
Jasper	1	58	84	178	175	52	39	145	125	42	28	53	46
Terre Haute	1	21	**	130	124	17	**	67	55	14		76	56
	2	49	70	134	130	49	31	145	108	43	41	107	76
	3	172	77	150	144	59	23	122	107	57	29	88	66
	4	52	71	150	141	41	25	106	98	40	26	99	64
	5	56	81	135	133								
	6					5478	37	717***					
	7	55	86	147	140								
	8	58	73	139	133								
	9	54	74	140	132								
Vincennes		49	70.0	185	172	44	25	85	76	39	32	69	58

* Number of Observations
** Insufficient Data
***Indicates One-Hour Readings

†Highest Value
††Second Highest Value

62 km NE of Grayville, which is the nearest point in White County to Vincennes.

In addition to the data summarized in Table 4-7, the highest reading for ozone in Evansville, Indiana, was 330 $\mu g/m^3$ and the second highest reading was 310 $\mu g/m^3$. The highest reading for carbon monoxide was 13,000 $\mu g/m^3$ and the second highest reading was 12,000 $\mu g/m^3$ for Evansville. These were the highest readings recorded in Air Quality Control Region Number 77 (16).

Table 4-8 is a treatment of the data gathered by the U.S. Department of Agriculture (17). Merom, Indiana, is approximately 100 km NNE of Grayville. The data represent 24-hour averages for the 10 days from March 3 to March 12, inclusive. The high degree of variability demonstrates that this type of data tends to fluctuate even in this short time span.

Figure 4-6 shows the annual trend for the geometric mean of the total suspended particulates at Evansville (Center City). No trend in these average values is evident.

4.2.4 Topography/Geomorphology

The general surface topography of Illinois has been influenced by successive periods of glaciation. Although White County is beyond the southernmost limit of the Wisconsin glacial period (about 20,000 years ago), it was subjected to the Illinoian stage of Pleistocene glaciation (over 100,000 years ago) and covered with the resulting Illinoian till (see Figure 4-7). The physiographic divisions of Illinois shown in Figure 4-8 reflect these various periods of glaciation (18).

TABLE 4-8. TWENTY-FOUR HOUR AVERAGE SULFUR DIOXIDE AND NITROGEN DIOXIDE LEVELS DURING MARCH 3, 1975 TO MARCH 12, 1975 AT THREE SITES IN SULLIVAN COUNTY, INDIANA (27)

(Units are Micrograms/Cubic Meter)

Site	Pollutant	Number of samples	Arith. mean	Geom. mean	Unbiased standard deviation	Range
A	Sulfur dioxide	10	33	27.	19.	8.0-61.9
	Nitrogen dioxide	10	6.	5.	3.	1.0-8.9
	Particulates	10	34.	31.	16.	17.6-68.7
B	Sulfur dioxide	10	18.	17.	7.	8.3-25.3
	Nitrogen dioxide	10	3.7	3.6	0.9	2.6-5.3
	Particulates	10	43.	35.	30.	14.1-106.9
C	Sulfur dioxide	10	10.	9.	5.	6.8-24.8
	Nitrogen dioxide	10	10.	9.	4.	3.5-15.4
	Particulates	10	40.	36.	17.	19.9-66.6
All	Sulfur dioxide	30	20	16.	15.	6.8-61.9
	Nitrogen dioxide	30	6.	5	4.	1.0-15.4
	Particulates	30	39.	34	21.	14.1-106.9

Site A is approximately 5.1 km ENE of Merom, Indiana. Site B is approximately 2.3 km NNE of Doddsville, Indiana, and Site C is approximately 3.1 km WSW of Paxton, Indiana. All are within 9 km of Merom. The concentrations of sulfur dioxide and nitrogen dioxide were significantly different at each site (p less than 0.05 using a t-test for related measures on each day's measurements). However, using the same criteria, the particulate counts were not significantly different except between Stations A and C.

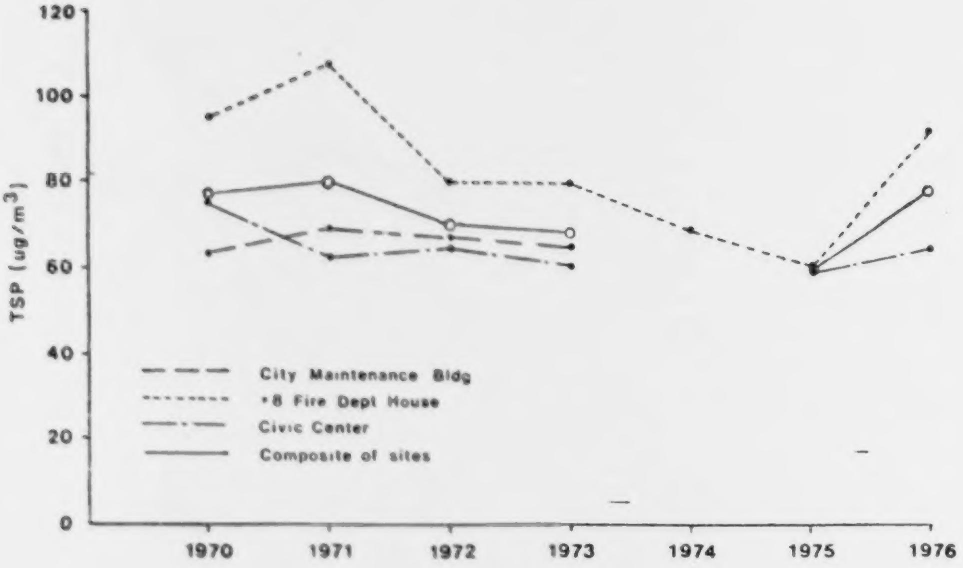


Figure 4-6. Total suspended particulate trend for Evansville (Center City), 1970-1976 (16)

Although covered with Illinoian till, the shallow depth of deposits in southern Illinois results in the topography being largely controlled by the underlying bedrock (19). White County is located in the Mt. Vernon Hill Country of the Central Lowland Province, an area characterized by low rolling hills and broad floodplains of low gradient streams (7).

The average land slope of White County is 4.16 percent -- a vertical change of 1.27 m in each 30.48 m of distance. The general elevation of the county is highest toward the northern extremities of the county; almost 140 m above mean sea level. The minimum elevation is found at the southern portion of the county where it is near 110 m above mean sea level. The general elevation is about 122 m above mean sea level (7).

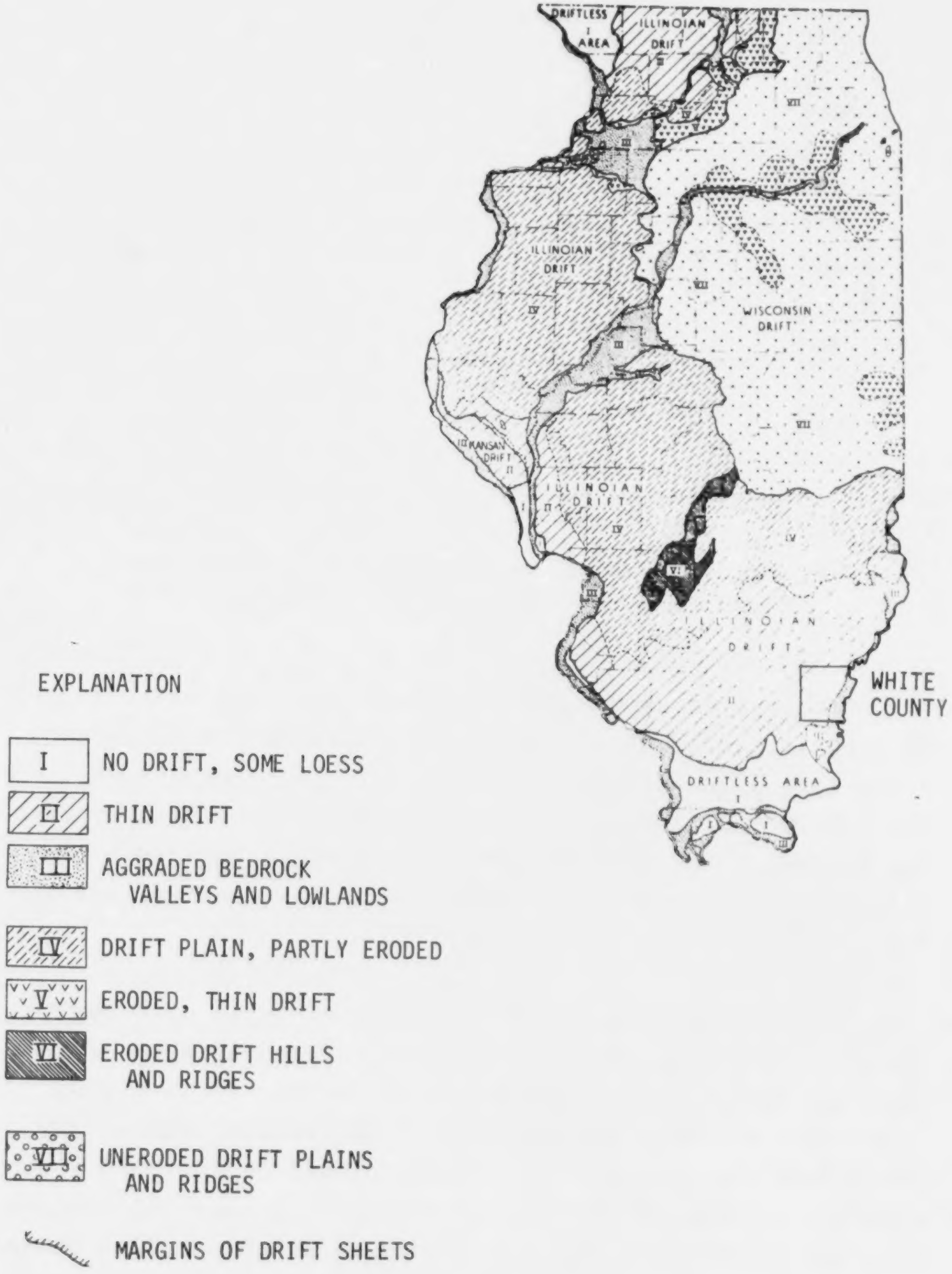

DRIFTLESS I AREA
ILLINOIAN DRIFT
WISCONSIN DRIFT
KANSAN DRIFT
ILLINOIAN DRIFT
ILLINOIAN DRIFT
ILLINOIAN DRIFT
DRIFTLESS AREA I
WHITE COUNTY
EXPLANATION
I NO DRIFT, SOME LOESS
II THIN DRIFT
III AGGRADED BEDROCK VALLEYS AND LOWLANDS
IV DRIFT PLAIN, PARTLY ERODED
V ERODED, THIN DRIFT
VI ERODED DRIFT HILLS AND RIDGES
VII UNERODED DRIFT PLAINS AND RIDGES
MARGINS OF DRIFT SHEETS

Figure 4-7. Distribution of glacial drift (9)

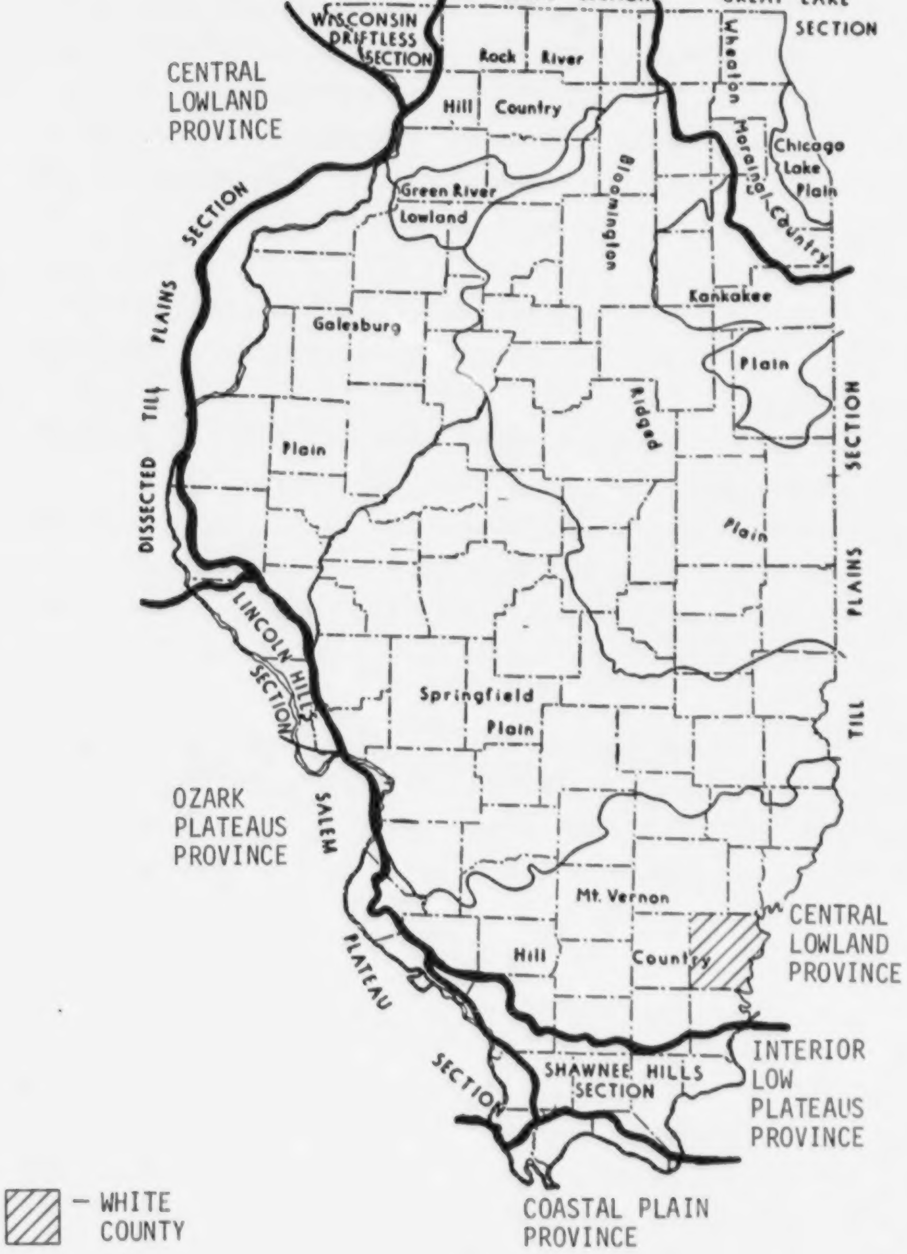

TILL PLAINS SECTION
GREAT LAKE SECTION
WISCONSIN DRIFTLESS SECTION
CENTRAL LOWLAND PROVINCE
Rock River Hill Country
Wheaton Morainal Country
Chicago Lake Plain
Green River Lowland
Bloomington Ridged Plain
Kankakee Plain
DISSECTED TILL PLAINS SECTION
Galesburg Plain
TILL PLAINS SECTION
LINCOLN HILLS SECTION
Springfield Plain
OZARK PLATEAUS PROVINCE
SALEM PLATEAU SECTION
Mt. Vernon Hill Country
CENTRAL LOWLAND PROVINCE
INTERIOR LOW PLATEAUS PROVINCE
SHAWNEE HILLS SECTION
COASTAL PLAIN PROVINCE
▨ – WHITE COUNTY

Figure 4-8. Physiographic divisions of Illinois (18)

The flood proneness of the Wabash River becomes a major consideration when evaluating the suitability of a particular site for the construction and operation of a coal liquefaction facility. After assessing characteristics of various areas, the northeast corner of the county was found to be the only sizable location within three kilometers of the Wabash River that is not located in the floodplain.

Flood-prone areas encompass one-third to one-half of White County. The areas delineated as flood-prone are considered to have 1 in 100 chances on the average of being inundated during any year, without consideration of present or future flood-control storage that may reduce flood levels. The normal non-flood elevation of the Wabash River is approximately 108 m at the northern tip of the county, decreasing to 105 m at the southern tip, with 100-year flood levels of roughly 116 to 119 and 113 to 114 m, respectively.

The large flood-prone areas of White County are significant not only in terms of the problems relating to the siting and construction of a large facility, but also in terms of the dissipative potential of various pollutants.

4.2.5 Geology and Soils

Figure 4-9 shows the four major subdivisions of geologic units in southern Illinois. These are the Precambrian basement rock, covered everywhere by from 610 to about 4,000 meters of consolidated sedimentary rock ranging in age from the Cambrian through Cretaceous. The Ordovician and Silurian rocks (Figure 4-9) are dominated by dolomite, the Mississippian by limestone, and the coal-bearing Pennsylvanian strata by shale and sandstone (1). Overlying these strata are glacial till, outwash, and windblown silt (loess) arising from continental glaciation during the Pleistocene

GEOLOGIC TIME UNIT		FORMATIONS	
		Illinois Basin	
		Northern	Southern
CENOZOIC	Quaternary	Till, Outwash, Loess	Loess
	Tertiary		Lafayette Wilcox Porters Creek Clayton
PALEOZOIC	Cretaceous		McNairy
	Pennsylvanian	McLeansboro Carbondale Tradewater-Caseyville	McLeansboro Carbondale Tradewater-Caseyville
	Mississipian	Valmeyer Group Kinderhook Group	Chester Group Valmeyer Group Kinderhook Group
	Devonian		Dutch Creek Clear Creek Bailey
	Silurian	Port Byron Racine Wakesha Joliet	
	Ordovician	Maquoketa Galena-Platteville Glenwood-St. Peter Praire du Chien	Maquoketa Thebes Lower Ordovician & Cambrian Strata
	Cambrian	Trempealeau Franconia Ironton-Galesville Eau Claire Mt. Simon	
PRE-CAMBRIAN			

Figure 4-9. Stratigraphic column of the Illinois basin in the Eastern Interior region (1)

age. Glacial till, consisting of well-sorted sands and gravels and unsorted till, has an average thickness of about 30 meters (1). The coal-bearing Pennsylvanian strata of southern Illinois are divided into four formations which are, in descending order, the McLeansboro, Carbondale, Tradewater, and Caseyville. The more important coal beds occur within a range of 210 meters in the middle (Carbondale) part of the Pennsylvanian system. The Carbondale group contains the Herrin (Illinois No. 6) and the Harrisburg (Illinois No. 5) seams, recognized as the most important coals in Illinois. The upper and lower parts of the McLeansboro group contain numerous coal beds rarely more than 0.7 meters thick, while the middle McLeansboro consists of limestone.

During the third major glaciation stage (i.e., the Illinoian) an extensive blanket of deposits was laid down, extending to within 32.1 km of the Mississippi Embayment in southernmost Illinois. The Illinoian glacial and loessial deposits of southern Illinois have weathered to produce the older soils (Alfisols) differing markedly in character from the younger soils of northeastern Illinois (known as Mollisols), which developed from the weathering of the Wisconsinan glacial till. The surficial geology of White County, Illinois, consists mostly of old lakebed sediments and the alluviated valleys and outwash plains along the Wabash River. Extensive wind erosion occurring among the Illinoian till and lakebed deposits resulted in the deposition of a rather deep loessal mantle.

The upland soils of White County consist predominantly of the Alfisols. These soils generally have a light-colored surface, or a mixture of light and dark surface layers that contain an average of less than one percent organic matter (20). The Alfisols have a recognizable B-horizon of clay accumulation.

The parent materials from which the White County soils have developed consist largely of deep windblown silt (loess) overlying the Illinoian till, except for the bottomland soils along the Wabash River which developed primarily from alluvium and fine sand materials. The soils derived from the loessial material are characteristically referred to as light-colored and dark-colored soils.

As of February 1978, the soils of White County were reported to be incompletely surveyed. However, detailed soil surveys of Wabash County (to the northeast) and of Gallatin County (to the south) have been completed; these provide detailed agronomic and engineering interpretations on many of the soil series found in White County. In addition to this, a general soil map was prepared for White County in 1969, showing nine main patterns of soil associations. The soils within any one association may differ in certain properties, such as slope, drainage, or color (20). Equally important, the general soil map provides engineering estimates of the suitability of the soil materials for building sites, highway location, fill material, and sewage lagoons, among other items (20).

Upland soils of White County are prone to damage from erosion by water (sheet and gully erosion) and by wind, particularly when disturbed or cleared during the construction of roads, feedlots, and oil production activities (21). For example, in the Pond Creek watershed of White County, the average annual soil loss per acre was reported to be 10 times greater from the oil production areas than from cropland. On the other hand, the loss of topsoil (sediment) from croplands emerges as the most critical soil erosion problem, because the total acreage of cropland vastly exceeds that in roads and oil production areas (21).

The most important soil association of White County, with regard to the siting of an SRC facility, is the Hosmer-Ava-Bluford group located southwest of Grayville and north of Crossville, Illinois. The soils of this group occur on the upland areas above the 100-year flood hazard, and range in slope from 4 to 12 percent. The suitability of the Hosmer-Ava-Bluford soils as fill material is generally poor to fair, due to their unfavorably high ratio between silt and clay and to their susceptibility to frost heaving. The Hosmer-Ava-Bluford soils comprise 68 percent of the association. The remaining minor soils (32 percent) include the Wellston, Stoy, Zanesville, and Belknap soils, all of which are poorly suited as fill material (20).

The second most important soil association is the Alford-Iva association, particularly that segment which extends from just south of Phillipstown, northward to Grayville, Illinois. The Alford soils comprise 76 percent of the association; these soils exhibit fair stability and compaction but are poorly suited as fill material because of the unfavorably high ratio of silt to clay. The Alford soils occupy ridgetops and sideslopes, and the slopes generally range from 4 to 12 percent, except for the sideslopes, which may exceed 12 percent (20).

The estimated limiting soil properties for building sites, septic tank and filter fields, sewage lagoons, highways, and drainage are shown in Table 4-9. All of these soils are susceptible to erosion by wind and water when cleared of vegetation and disturbed by excavation and grading activities (20).

The Alvin-Lamont-Ruark, and the Patton-Reesville-Camden associations of eastern White County occupy the stream terraces along the Wabash River. These terraces range from only meters to about 15 m above the floodplain elevation and thus pose a risk from flooding in the low-lying areas. However, the Alvin and Lamont soils are considered to have fair to good suitability as fill material. On the other

TABLE 4-9. ESTIMATED SOIL LIMITATIONS FOR ENGINEERING USES OF WHITE COUNTY SOILS (20)

Soil Association	Soil Series	Percent of Association	Building Sites	Sewage Lagoons	Highway Location	Pond Reservoir	Pond Embankment Material	Drainage
Alford	Alford	76	Moderate[a,b] Severe[c]	Moderate[a,d,e] Severe[f]	Moderate[a,g] Severe[h]	Moderate[d]	Moderate[a]	Slight
Iva	Iva	22	Moderate[i,j]	Slight	Moderate[i,j]	Moderate[k]	Moderate[a]	Moderate[d,i]
Hosmer	Hosmer	34	Moderate[a,j] Severe[g]	Moderate[a,e] Severe[f]	Moderate[a,g,j]	Slight	Moderate[a]	Slight
Ava	Ava	17	Moderate[a,j]	Moderate[a,e] Severe[f]	Moderate[a,j]	Slight	Slight	Slight
Bluford	Bluford	17	Moderate[i,j]	Slight to Moderate[c]	Moderate[i,j]	Moderate[k]	Slight	Moderate[i,l]
Alvin	Alvin	35	Slight to Moderate[b] Severe[c]	Severe[m,n]	Moderate[g] Severe[h]	Severe[m]	Severe[a,m]	Slight
Lamont	Lamont	33	Moderate[b,o]	Severe[m,n]	Moderate[o]	Severe[m]	Severe[a,o]	Slight
Ruark	Ruark	18	Severe[j,p]	Severe[n]	Severe[j,p]	Severe[m]	Moderate[a,m]	Severe[i,p]
Patton	Patton	23	Severe[j,p,r]	Moderate[d,p]	Severe[j,p,r]	Moderate[k]	Moderate[a]	Severe[d,p]
Reesville	Reesville	21	Moderate[i,j]	Slight	Moderate[i,j]	Moderate[k]	Moderate[a]	Moderate[d,i]
Camden	Camden	17	Moderate[a,b] Severe[c]	Moderate[a,d,e] Severe[f]	Moderate[a,g]	Severe[d,m]	Moderate[a]	Slight
Allison	Allison	34	Severe[q]	Severe[q]	Severe[q]	Moderate[k,q]	Moderate[a]	Slight
Tice	Tice	34	Severe[i,q,r,s]	Severe[q]	Severe[i,q,r]	Moderate[k,q]	Moderate[a]	Moderate[d,q]
Beaucoup	Beaucoup	26	Severe[l,p,q,r]	Severe[q]	Severe[p,q,r]	Moderate[k,q]	Moderate[a]	Severe[p,q]

[a] Fair stability, compaction and resistance to piping

[b] Slope 4-12 percent

[c] Slope greater than 12 percent

[d] Moderate and moderately slow permeability

[e] Slope 2-7 percent

[f] Slope greater than 7 percent

[g] Slope 12-18 percent

[h] Slope greater than 18 percent

[i] Seasonally high water table at 1-2 feet below surface

[j] Susceptible to frost heave

[k] Slope 0-4 percent

[l] Slow permeability

[m] Rapid permeability below 3 feet

[n] Contamination hazard to nearby water supplies

[o] Unfavorable sand content

[p] Seasonally high water table at or near the surface

[q] Flooding hazard

[r] High shrink-swell potential

[s] Unfavorable clay content

hand, the Patton and Reesville soils have a high shrink-swell potential and are relatively poor as fill material (20).

4.2.6 Climate

White County has a continental climate, typical of Illinois, which means hot summers and cool winters. The average January temperature is 1°C and the average July temperature is 26°C. The average annual temperature is

13°C. Climate data are not specific for record days; however, the all-time high for this area was recorded at Fairfield, Illinois, during July 1964, when the temperature reached 45°C. The all-time low temperature recorded at Fairfield was a -30°C during January 1963 (22).

Average annual evaporation from open-water surfaces is between 76 and 97 cm. Potential evapotranspiration annually averages about 84 cm (23, 24, 25).

The mean annual rainfall at Carmi is 102.8 cm. Approximately 60 percent of the rainfall occurs during the warmer half of the year. May is the month having the most precipitation (11.3 cm) and October has the least (7.24 cm). Snow is accumulated annually from 25-36 cm. Snowfall may occur any time from October through April (23).

Most wintertime precipitation occurs when storms move eastward. Comparatively small differences in the spatial distance of these storms often determine whether the precipitation is snow, rain, or freezing rain. Snowfall varies greatly from season to season, as do rainfall and temperature. Average annual snowfall is approximately 33 cm, with snowfall amounting to more than 2.5 cm occurring approximately 4 days each year (26).

The average growing season is 190 to 200 days in length. The average date of the last killing frost in the spring is April 13 and the average date of the first killing frost in the fall is October 23 (22).

Evansville, Indiana, is the closest station for which local climatological data are available from the National Oceanic and Atmospheric Administration (NOAA). The latest annual summary with comparative data (for 1976) is given in Appendix Table A-V-1.

The annual prevailing wind direction is from the south-southwest with a mean annual wind speed of 13.4 km per hour. Average wind speeds are approximately three-fourths this value in summer, and approximately one-fourth higher than this value in spring. Winter prevailing winds are from the northwest. The maximum observed wind speed was recorded in February of 1956 at 95 km per hour from the west (24).

In the area of White County the average annual afternoon mixing depth is approximately 1.5 to 2.0 km. The afternoon mixing depth represents the maximum height above the earth's surface to which active dispersion of pollutants takes place during the daily cycle (27).

Average annual wind speed through mixing depth is approximately 8 meters/sec. The average afternoon ventilation is:

Spring:	ca. 18×10^3 m^2/sec
Summer:	$6\text{-}12 \times 10^3$ m^2/sec
Fall:	$6\text{-}12 \times 10^3$ m^2/sec
Winter:	$6\text{-}12 \times 10^3$ m^2/sec

The afternoon ventilation is the product of the mixing depth and the average wind speed through the mixing depth. This value is proportional to the volume of air available to dilute pollutants emitted into the atmosphere. More specific information may be available from the National Center for Air Pollution Control (27).

The role of atmospheric factors in dissipating or exacerbating the potential environmental effects of pollutants is discussed at length in Chapter 5.

4.2.7 Historic Landmarks and Trails

The Illinois Historic Sites Survey has reported that White County possesses 20 important historic structures, 10 historical markers, 22 centennial farms and one historic trail (28). Essentially all of the structures and markers are found within township limits, as shown in Appendix Table A-IV-1.

The Shawneetown-Vincennes Trail passes north through New Haven and then runs parallel to and east of Illinois Route 1 slightly north of Carmi, all of the way to Grayville, Illinois. No historic structures have been reported for the area north of Crossville to Grayville.

4.2.8 Historic Archeological Sites

Archeological surveys made in the Wabash Valley by the Illinois State Museum date from 1933. In the 1962 survey, as well as in earlier surveys, the coverage of White County was relatively spotty. However, a full range of culture areas, from Paleo-Indian to protohistoric, has been identified in the Wabash Valley (29). Three new sites were surveyed in White County in 1962. Two of these were located in the northeastern corner of the county, and one was located along the Little Wabash River in the north-central part of White County. Present evidence suggests that the archeological resources occur predominantly in areas adjacent to the Wabash River, generally at a distance of 3.2 km or less from the shoreline. These sites occur primarily at the middle and lower segments of the Wabash River shoreline. Thus, the specific site for the coal liquefaction facility should be evaluated for archeological significance, to see if significant archeological artifacts can be preserved before construction begins.

4.2.9 Industries (22)

While agriculture is basic to the economic structure of White County, oil production has been very important also. During 1955, the county ranked first in the state in both drilling and production. About half of the production in 1955 (estimated at 80,000 m^3) came from two pools: the White County portion of Roland Consolidated and the New Harmony Consolidated. The 27 other pools in the county produced 80,300 m^3 of oil in 1955. The oil boom of the 1950s has passed, and the majority of oil recovered currently is by water flooding.

Industries located in White County include Carmi-Aensbrooke Corporation, located in Carmi, manufacturing men's underwear; and Sterling Aluminum, Division of Federal-Mogul Corporation, manufacturing pistons.

4.2.10 Transportation

Transportation through the county is by U.S. Routes 460 and 45, and Illinois State Route 1. White County has 130 km of paved roads and 1,300 km of all-weather roads making transportation in and out of the area good. The Carmi Municipal Airport is located 1.6 km northeast of Carmi. Rail transportation is by the Louisville and Nashville Railroad which runs from the southeast through Maunie to Carmi then westward through Enfield. The Baltimore and Ohio Railroad runs north and south along the western edge of the county paralleling Route 45.

4.3 Characterization of Existing Biotic Features Having Relevance to Potential Adverse Environmental Effects

4.3.1 Fish and Wildlife Resources

The natural areas of Illinois have had a great amount of human alteration within historic times. Many natural habitats have been transformed into cities or cornfields, others greatly reduced in extent, and still others variously modified from their original condition. In a sense, all of the habitats are relictual, separated from each other by expanses of cultivated fields (30). The land area of White County is mainly devoted to agriculture and old oil fields; there is little woodland. In 1977, about 70 percent of White County was devoted to agriculture (31).

4.3.1.1 Terrestrial Flora

The main type of natural vegetation in the White County region is the oak-hickory forest and other characteristic tree species such as white ash, sweet gum, swamp white oak, burr oak, and swamp cottonwood (32).

Oak-hickory forests are widely distributed, but generally limited to slopes of shallow ravines or low morainal ridges. Within areas of the oak-hickory forest type, the bottomlands are composed of an admixture of mesophytic forest species and flood-plain species including walnut, ash, elm, burr oak, honey locust, silver maple, white elm, cottonwood, and sycamore. In the upland forests of this type, the predominant trees are pin oak, shingle oak, birch, honey locust, post oak, and blackjack oak (26).

The dominant shrubby ground covers under the oak-hickory and associated forest types include: mountain laurel, rhododendron, dogwood, wisteria, spicebush, buttonbush, fragrant sumac, blueberry, buckthorn, smooth alder, hawthorn, and others. Plants seen in wetland and river bottom areas include spike rush, beak rush, various sedges, swamp milkweed, marsh fern, swamp rose, beggarticks, cattail, water primrose, and lizard's tail (32).

A relatively more complete list of the plant species can be found in Appendix Table A-IV-3.

4.3.1.2 Phytoplankton and Zooplankton

Phytoplanktonic populations observed in 1975 in a 4.8 km reach of the Wabash River just downstream of Merom, Indiana, were dominated by diatoms. The dominance of riverine phytoplankton by diatoms is typical of larger rivers. Pennate diatoms appeared to peak in the Wabash River during May, while centric diatoms appeared to peak during October. Total populations during February were on the order of 100,000 cells/l; during May, on the order of 300,000 cells/l; during August, just less than 200,000 cells/l; and during October, on the order of 300,000 cells/l. It has been suggested that periodic blooms of diatoms can contribute significantly to the high turbidities of the Wabash River during the summer (17).

Zooplanktonic populations in 1975 just downstream from Merom consisted primarily of rotifers and stalked or colonial ciliates, with relatively few crustaceans. The dominant genera were the rotifers Platyias during winter, Keratella in the spring, and Brachionus in the summer and fall. Larger numbers of species (from 14 to 35) were observed in the winter-spring period, and smaller numbers (from 8 to 16) observed in the summer and fall. Total zooplanktonic populations were typically on the order of 10 organisms/l, ranging from 3 organisms/l to about 45 organisms/l. These populations were significantly less than total phytoplanktonic populations observed in the Wabash River during the same period. This is consistent with the results of other investigations of the plankton of larger rivers (17).

The periphyton of the Wabash River were examined (using artificial substrates) at three locations in the vicinity of the Wabash River Power Plant just north of Terre Haute. Fifty-four genera were identified during this 1971 study. The groups most commonly represented, in order of abundance, were the blue-green algae, green algae, and diatoms. The temperature change created by the power plant did not appear to exceed the tolerance limits for most periphyton. Population densities of a number of types (particularly the blue-green algae) appeared to increase as a result of the hot water coming from the power plant (17).

Lin and coworkers (33) surveyed the plankton populations in several tributaries to the Wabash River in and around White County; their data are summarized in Appendix Table A-IV-4. Also shown is the maximum percent composition of blue-greens, greens, and flagellates for each sampling location. The maximum for diatoms was 100 percent at each station, i.e., at one time or another all plankton in a water sample for each station consisted solely of diatoms (33).

An examination of the plankton density data, expressed as cell counts per milliliter (cts/ml) for each station, showed them to be generally distributed in a log-normal pattern. Therefore, the central tendency and dispersion of the data have been expressed in geometric terms (33).

The geometric mean (m_g) values at most locations were not significantly different from year to year, except when a sample did not contain algae. This happened frequently during winter months, especially during January and February. Also, the geometric standard deviation (σ_g) becomes quite large if samples with no algae are included in the computations (33).

The number and types of plankton in running water depend upon many factors. Among them are size and shape of the stream, temperature, stream velocity, depth, light penetration, nutrient availability, grazing animals, and human activity. Thus, it is extremely difficult to reasonably predict the population and composition of plankton in streams (33).

4.3.1.3 Benthic Macroinvertebrates (Except Clams and Mussels)

The observed benthic population of the Wabash River and its tributaries varied from approximately 215 organisms/m^2 to over 11,000 organisms/m^2, depending on location and time of year (17,26); however, the most frequently recorded densities were less than 1,100 organisms/m^2.

There is an appreciable diversity of benthic macroinvertebrates in the sandy substrates of the Wabash River. Although oligochaete worms and insect larvae form the bulk of the benthic populations, crustaceans, pelecypods and gastropods are also found. Substrate textures are sandy gravel, with gravel proportions ranging from 20 percent to over 80 percent of the total sample. However, no clear relationship between substrate type and benthic organism density was found. Substrates do not seem to be a controlling factor in benthic numbers (17,26).

A listing of the macroinvertebrates, with the exception of clams and mussels, which occur in the Wabash and/or its tributaries in or near White County, can be found in Appendix Table A-IV-6.

4.3.1.4 Mussels and Clams (22,26,34,35)

Intensive agricultural practices have involved the clearing and plowing of more and more land. Thus, during spring run-off or at flood periods, tremendous quantities of topsoil are washed into streams and rivers, causing layers of silt and mud to settle and cover the former sand and gravel bottoms. Species such as clams and mussels, adapted to a sand and gravel bottom environment, cannot long survive in one composed of mud and thus are quickly destroyed by the smothering effects of silting.

Compared with pollution and silting, the two major kinds of natural enemies -- parasites and non-human predators -- generally have little overall effect on any given population of mussels. Probably the most common non-human mammal predator is the muskrat; piles of shells around muskrat houses and entrances to their burrows in mud banks attest to the gathering activities of these rodents. Raccoons, mink, and otters, as well as some species of birds (especially waterfowl), also utilize mussels for food. The fresh-water drum or sheepshead feeds almost exclusively on them.

Modern man's extensive use of the fresh-water mussel has centered around the shells as a source of raw material for the manufacture of pearl buttons and pellets in connection with the cultured pearl industry. Since 1967 the mussel harvest has fallen off drastically due to overfishing of the slow-growing mussels and a lessening of the demand.

In time, should the pearl industry recover from a slump and require more shells, it may become necessary to close sections of the Wabash River to permit continued mussel reproduction and growth. Gravel dredging operations at several locations along the river destroy much of the mussel habitat, necessitating restrictions if the mussels are to thrive.

Krumholz and coworkers (34) studied the mussel distribution along a 16.1 km section of the Wabash River between Delphi and Terre Haute. They compared the mussel catch in 1966 and 1967 in each 1.6 km section. They found that the number of specimens (1966 avg: 18.4/km, 1967 avg: 3.47/km) and the number of individual species (1966 avg: 1.3/km, 1967 avg: 0.68/km) differed significantly (Student's t-test for related measures: df: 9, $t = 4.261$, p = less than 0.01 and $t = 5.752$, p = less than 0.001, respectively). A similar t-test using the number of individuals in this 16.1 km stretch of each species taken showed a significant decrease from 1966 to 1967 (avg: 8.4 individuals per species per km in 1966 and 1.6 individuals per species per km in 1967; $t = 2.482$; p = less than 0.05). The t-test is a statistics technique used to determine if two sets of data are significantly different. In this contex, "df" refers to degrees of freedom and is equal to the number of paired observations minus one; "t" is the numerical result of the Student's t-test for paired measures. The "p" refers to the possibility that no significant differences exist, that is, a $p = 0.01$ means that there is one chance in 100 that no significant difference exists or that there are 99 chances out of 100 that the observed difference is real. Insignificance (p greater than 0.1) by this criteria should not be construed to imply that the observed trend is not real. A "p" of 0.1 indicates that there is one chance in ten that the observed difference is artifactual, or that there are nine chances in ten that the observed difference is real. Probabilities ("p") in the range of 0.1 to 0.9, by convention, mean little. A "p" of 1.0 means the two sets of data are identical. The species diversity index (calculated using the formula described in the fish section) decreased from 3.01 in 1966 to 2.69 in 1967. The decline was possibly due to the introduction of scuba equipment for mussel harvesting and resultant overharvesting. Scuba gear has since been banned in commercial mussel harvesting, but the introduction of the Asiatic Clam (Corbicula fluminea) may now be effectively delaying or preventing the numerical recovery of the commercial species. In 1965, 1,800 Mg of Indiana shells were sold for use in Japan; in 1966, that number was 3,800 Mg; in 1967, it was 980 Mg; and in 1968 the total probably did not exceed 230 Mg.

A listing of the mollusks found in the Wabash River or its tributaries in or near White County can be found in Appendix Table A-IV-7.

4.3.1.5 Commercial and Sport Fish

Fishing in White County is done for both sport and commercial species. Currently about a tenth of the residents of White County purchase a non-commercial fishing license (23), and there are approximately 450 licenses sold annually permitting the use of commercial fishing gear. The most important sport fish species are the largemouth bass, bluegill, and channel catfish. To improve and maintain the sport fishery of the county, the Illinois Department of Conservation provides fingerling largemouth bass and bluegill to new or rehabilitated water areas (22).

The important commercial fish include carp, freshwater drum, channel catfish, flathead catfish, blue catfish, and bullhead catfish. Other commercial species generally not taken by sporting equipment include the buffalo, sturgeon, paddlefish, quillback carpsucker, and other sucker species. Gar, bowfin, and eel are occasionally sold commercially (22).

The fish population of the Wabash River bordering Illinois was sampled by electro-fishing at 18 stations during August 1967 (22). A total of 45 species of fish were collected by electro-fishing and seine hauls. There were 3,006 fish weighing 1,134 kg sampled by the electro-fishing method. Minnow seine hauls collected 1,050 miscellaneous minnows. Game fish were collected on an average of 0.6 fish per minute of electro-fishing. Spotted bass represented 44 percent of the total number of game fish collected and 28 percent of the total game fish weight. Commercial fish were collected at a rate of 0.7 fish per minute of electro-fishing. Carp composed 57 percent of the total number of commercial fish collected and 93 percent of the total weight. Forage fish were collected at a rate of 2.1 fish per minute of electro-fishing and consisted primarily of gizzard shad; by number 99 percent and weight 98 percent. In all 18 stations, forage fish represented 62.4 percent of the total number of fish collected, commercial fish 20.7 percent, and game fish 16.9 percent. By weight, commercial fish represented 66.5 percent of the total, forage fish 25.4 percent, and game fish 8.1 percent (22). A more complete summary of the kinds and amounts of commercial fish caught during the period 1956-75 is found in Appendix Table A-IV-8.

With regard to the Little Wabash River System, Smith (37) reports that the pollution rating is poor in the lower reaches, but very good in upper part of the system; he found 78 species present. The problems are oil-field pollution, siltation, and desiccation during drought periods.

Tributaries such as the Skillet Fork, Elm River, and Fox River are low-gradient, brushy streams with oil pollution and very low species diversity. The Little Wabash River between Louisville and Neoga has alternating pools and sand or sand-gravel riffles and high species diversity. Unusual species include: spotted bass, bigeye shiner, greenside darter, and dusky darter. Tributaries in the upper portion of the basin are shallow, sandy streams with fair species variety; the headwaters of the Little Wabash above Lake Mattoon are badly silted (36).

Table A-IV-9 of the Appendix shows the spawning habits of some of the more common species. A complete listing of all fish species, including Latin names, likely to be encountered in the Wabash River or its tributaries, is found in Appendix Table A-IV-10.

A useful approach to evaluating the response of an ecological community to an environmental stress is to compute an index of species diversity. The Shannon-Weaver index for mean diversity, D, is defined as:

$$D = \frac{3.321928}{N} (N \log_{10} N - \Sigma n_i \log_{10} n_i)$$

where:

N = total number of individuals in a sample and

n_i = number of individuals in the i^{th} species.

This index of diversity has a species richness component and an evenness component that refers to the distribution of individuals among species. The maximum value for evenness, D_{max}, occurs when all of the species are equally abundant, while the minimum value, D_{min}, occurs when all the species but one are represented by a single individual with the rest of the sample being composed of the dominant species. Computationally, the evenness component is calculated by evaluating $(D_{max} - D)/(D_{max} - D_{min})$. The value for evenness varies between zero and one.

Environmental stress may influence either the species richness (number of species) or the evenness components of the diversity index. The diversity index should not be calculated for samples containing less than 100 individuals. Highly stressed systems often have mean diversity indices less than one, while unstressed systems in a biologically rich area have diversity indices ranging from three to four. A paradox is that low-diversity systems are often dominated by organisms with large population size, high reproductive rates, and high genetic variability. Such populations are likely to contain some members capable of adapting to environmental stresses. Stream biota live in a fluctuating physical environment and thus generally have low diversity. Such communities have good capacity for compensating moderate levels of environmental stress.

The fish diversity index of many fish surveys has been calculated according to the previous formula for the Wabash River, the Little Wabash River and other tributaries. The results of these calculations are presented in Appendix Tables A-IV-11, A-IV-12, and A-IV-13. These diversity indices are generally greater than two and indicate a healthy ecosystem.

A second indication of a healthy ecosystem is the increase in the different kinds of species found in the Wabash River. A listing of the species which may have disappeared from the Wabash, and those which may have appeared, is found in Appendix Table A-IV-14. This gives a second indication that the Wabash is a viable ecosystem.

Unfortunately other, more reliable *evidence* (Table 4-10), indicates that the number of fish in the Wabash is decreasing. The likelihood that an observed decrease in a measured parameter is significant was calculated by Student's t-test for related measures (discussed previously) on the number and kinds of species collected at each of 18 collection stations (in most cases). One very alarming result of this calculation is that the percent of the total number of sport fish of catchable size collected by electrofishing, increased significantly from 37 percent in 1967 to 61 percent in 1975, indicating possible reproductive failure. Other trends which indicate a deteriorating ecosystem are the reduction in the weight of commercial and forage fish caught per hour of electro-fishing. The numbers of game (p less than 0.001), commercial (p less than 0.001), and forage (p less than 0.001) fish collected per hour of electro-fishing also were significantly reduced. The decrease in the forage fish should be alarming, since these fish serve as food sources for some game and commercial fish. This apparent partial expunging of fish species is apparently not due to the small change in pH, especially since the observed change is toward a more neutral condition.

4.3.1.6 Amphibians (30)

There are 21 species of the order Salientia (frogs and toads) in Illinois. Members of the order Salientia may be divided into three rather artificial groups: the true frogs, the toads, and the treefrogs. The true frogs, in general, are terrestrial, but they are forced to remain near water because of their rapid rate of dehydration. The toads are

TABLE 4-10. CHANGES IN DIVERSITY INDEX, PH, ALKALINITY, TOTAL NUMBER, AND WEIGHT OF FISH CAUGHT ALONG THE WABASH RIVER IN OR NEAR WHITE COUNTY

Parameter	Group 1	Group 2	Group 1 Mean	Group 2 Mean	df	t	p
Diversity index (Table A-IV-8) for electrofishing	1975 values	1977 values	2.493	3.000	6	-1.494	> 0.10
pH	1975 values	1977 values	7.9	7.7	6	1.075	> 0.10
	1967 values	1975 values	8.1	7.9	17	1.356	> 0.10
	1967 values	1977 values	8.2	7.7	6	2.441	> 0.05
Percent of total number of "commercial fishes" 33.02 cm and over in total length collected by electrofishing							
Carp	1967 values	1975 values	97%	94%	16	1.710	> 0.10
Channel catfish	1967 values	1975 values	74%	55%	5	1.109	> 0.10
Flathead catfish	1967 values	1975 values	50%	38%	8	0.532	> 0.50
River carpsucker	1967 values	1975 values	46%	82%	7	-2.046	> 0.05
Freshwater drum	1967 values	1975 values	19%	31%	8	-0.712	> 0.10
Total of all fishes	1967 values	1975 values	69%	72%	17	-0.548	> 0.5
Percent of total number of "sport fishes" of a "catchable size" collected by electrofishing							
Channel Catfish	1967 values	1975 values	70%	55%	4	0.870	> 0.10
Flathead catfish	1967 values	1975 values	55%	39%	9	0.783	> 0.10
Spotted bass	1967 values	1975 values	23%	67%	10	-3.009	< 0.02
White crappie	1967 values	1975 values	22%	56%	2	-1.000	> 0.10
Bluegill sunfish	1967 values	1975 values	31%	76%	4	-1.607	> 0.10
Freshwater drum	1967 values	1975 values	43%	63%	8	-1.308	> 0.10
Total of all fishes studied	1967 values	1975 values	37%	61%	17	-3.620	< 0.01
Pounds of fishes collected per hour of electrofishing							
Game	1967 values	1975 values	13.47	8.49	17	1.985	> 0.05
Commercial	1967 values	1975 values	115.23	63.54	17	2.763	< 0.02
Forage	1967 values	1975 values	45.43	11.29	17	5.652	< 0.001
Total	1967 values	1975 values	174.13	83.32	17	4.806	< 0.001
Numbers of fishes collected per hour of electrofishing							
Game	1967 values	1975 values	35	14	17	5.467	< 0.001
Commercial	1967 values	1975 values	44	25	17	3.663	< 0.01
Forage	1967 values	1975 values	132	43	17	4.819	< 0.001
Total	1967 values	1975 values	211	82	17	6.849	< 0.001
Total Alkalinity	1975 values	1977 values	129	105	6	1.709	> 0.1

more resistant to desiccation and may occur far away from ponds and streams. The treefrogs also are fairly resistant to desiccation and they are usually arboreal in habits. Nineteen species of the order Caudata (salamanders) have been reported in Illinois.

Appendix Table A-IV-15 lists the species of amphibians which have been found, or are likely to be found in White County.

4.3.1.7 Reptiles (30,37)

The reptiles which are found or are likely to be found in White County are listed in Appendix Table A-IV-16. The reptiles may be divided into the orders Testudines (turtles) and Squamata. The order Squamata may be divided into two suborders, Sauria (lizards) and Serpentes (snakes).

Seventeen species and subspecies of turtles occur in Illinois. Turtles found in Illinois are, with the exception of the box turtles, primarily aquatic in habit. They range in size from the 10 cm, 100 gm musk turtle to the 60 cm, 110 kg alligator snapper. Most Illinois turtles are primarily carnivorous in their food habits, utilizing as food insects, insect larvae, fish, crayfish, earthworms, snails, and occasionally carrion. Turtles themselves are used by man for food; the snapper, soft-shelled turtle, and diamond-back terrapin being especially desirable for table use.

Only six species of lizards are known to occur in Illinois and, as is true of most lizards, they are terrestrial or land-dwelling in habit.

Forty-six species and subspecies of snakes are known to occur in Illinois. Snakes are extremely variable in habits and structure. In general, the crotalids (Crotalus, Sisturus, and Aqkistrodon) and natricines (Natrix, Thamnophis, Storeria, Virginia, and Tropidoclonion) are active day or night, and the colubrines (the remaining genera) tend to be diurnal. The majority of Illinois genera are terrestrial; some are fossorial; a few are aquatic; still fewer are arboreal. In size, they range from the 25 cm Tantilla gracilis to the 2 meter Pituophis melanoleucus. Snakes are rather specialized in feeding habits, some taking only one or two specific types of prey.

Four species of poisonous snakes, the copperhead, the cottonmouth moccasin, the timber rattlesnake and the massasauga are found in Illinois, although not commonly. Only in areas devoid of intensive agricultural practices such as the river bluffs and marshes can these forms be expected to maintain themselves.

4.3.1.8 Birds (22,26,32,38,39)

The bird species and their habitats in White County are found in Appendix Table A-IV-17. Also shown is the relative abundance of each species observed in a bird count performed in White County on May 8, 1976. The percentage of each species observed does not add up to 100 percent since the calculation was only carried one place past the decimal point. As indicated by blank spaces, many species whose range includes White County were not observed. Some of these missing species may have been migrants who had not yet arrived in White County. Others may have been missed because they are rare in White County or because they were not active in their habitat when the observer was present. The diversity index (calculated using the formula displayed earlier for fish) was 5.261 with 82 species and 691 individuals being observed.

More than 25 species of waterfowl migrate along the flight lanes which parallel the Wabash River. Major waterfowl include the mallard, pintail, and black duck, comprising 80 percent of the migratory waterfowl population. The wood duck is the only migratory waterfowl species that uses the area as a nesting ground. Other migratory waterfowl passing through the area include the bluewinged teal, gadwall, shoveler, red head widgeon, scaup, greenwinged teal, canvasback, ringneck, coot, American widgeon, rail duck, and the blue, snow, and Canada goose. Other game birds of the region include the mourning dove and quail. Waterfowl hunting is limited to occasional wet seasons.

Important non-game birds found in the Illinois area include the red-tailed hawk, turkey vulture, black vulture, great horned owl, and green heron. Smaller birds of importance include the chimney swift, cardinal, indigo bunting, mockingbird, scarlet tanager, downy woodpecker, crow, bluejay, belted kingfisher, barn swallow, American goldfinch, tufted titmouse, brown thrasher, and Nashville warbler.

4.3.1.9 Mammals

Between 2,500 and 2,700 persons purchase an annual license to hunt small game in White County. Of primary interest to the hunters are rabbits, squirrels, and quail. The rural and physical aspects of the county meet the habitat requirements of these game species. For rabbits and quail, the small farm units with grown-up fence rows are most desirable. Both red and gray squirrels are found in the wooded river bottoms. Fox and coon hunting is also practiced. The trapping of fur-bearing animals is undertaken for sport and does not contribute to the economics of the county. Animals such as muskrat, mink, and fox are sought by the trapper to supplement other income, but primarily afford recreation.

A listing of mammals which may occur in White County can be found in Appendix Table A-IV-19. A summary of the small game hunting can be found in Appendix Table A-IV-20; this latter table shows that White County small game hunters are generally more successful than the average Illinois small game hunter.

4.3.2 Rare and Endangered Species

In the context of this report, the term rare means the species is restricted in its range and/or numbers. Endangered means that extirpation of the species from Illinois is highly possible. Threatened implies that the species could possibly become endangered, if it is not so already.

A species may be rare due to various circumstances. Man's direct influence upon the environment has reduced some species to a single locality or several relict populations. Excessive harvesting and the destruction of habitat are major reasons for species becoming endangered.

4.3.2.1 Rare and Endangered Species Whose Range Includes White County (24,40)

A listing of rare and endangered species which may be found in White County is found in Appendix Table A-IV-21. This listing also includes some comments on the habitat and life history of some of these species. Of these rare and endangered species, the hellbender and the alligator snapping turtle have been seen in White County. Higgin's eye pearly mussel, the river chub, northern madtom, hellbender, alligator snapping turtle, hieroglyphic turtle, and hooded merganser have been found in the Wabash River. The harlequin darter lives in the Embarrass River. The bigeye shiner and bigeye chub are found in the Little Wabash River, and the northern madtom, bluebreast darter, bigeye chub, bigeye shiner, and river redhorse are found in the Vermilion River.

4.3.2.2 Factors Responsible for Changes in Illinois Fish Populations (36)

Excessive siltation ranks first and is implicated as the principal cause for the extirpation of two native species and the decimation of 14 others. Its effects include loss of water clarity and subsequent disappearance of aquatic vegetation, coupled with deposition of silt over substrates that were once bedrock, rubble, gravel, or sand. Feeding and spawning sites, as well as the usual habitats for such fishes, have been reduced over much of Illinois.

Drainage of natural lakes, sloughs marginal to large rivers, swamps, and prairie marshes ranks second in importance and is responsible for the shrinkage in the range of 13 native species of Illinois.

Desiccation of stream systems during drought periods ranks third in importance and is responsible for the shrinkage in range of 12 species. In recent decades, the water table has fluctuated more widely than it did before 1930. During severe late summer and fall drought, streams that were once permanently flowing now dry up, seeps and springs cease to flow, and some relatively large rivers temporarily become medium-sized or small streams. Stream desiccation is a relatively new factor that has had its most devastating effects since 1930. Prior to that year, droughts had less effect because the water table was less variable.

Species interaction following modification of a stream or watershed ranks fourth in importance and is responsible for the extirpation in Illinois of the Ohio lamprey and the rosefin shiner, and the decimation of seven other species. Prior to 1917, the Ohio lamprey occurred in the Wabash watershed, but the allied and allopatric chestnut lamprey has since supplanted the Ohio lamprey in all of eastern Illinois and western Indiana. The rosefin shiner occurred in extreme southeastern Illinois in the last century but has been supplanted in Illinois and adjacent Kentucky by the more ecologically tolerant and allopatric redfin shiner.

Pollutants other than sediment (e.g., industrial, domestic, and agricultural pollutants) rank fifth in importance and can be implicated in the extirpation of two, and the decimation of five Illinois fishes. Virtually all of the streams and lakes in Illinois have been affected to some degree by pollution. Among the most dramatic illustrations is the degradation of the lower Little Wabash system because of oil-field pollutants.

Fish kills have occurred repeatedly when toxicants such as anhydrous ammonia and cyanide have been accidentally or deliberately dumped into streams. In most cases the streams are repopulated in two or three years, but endemic species cannot return once the population has been eliminated, since, by definition, such a species is unique to an environmental area and exists nowhere else, making restocking impossible.

The revelation that water pollution ranks fifth among the principal causes for extirpation and decimation of native fish is rather surprising. However, many fish are remarkably resistant to some degree of pollution as long as the physical habitat remains intact. Also, in many parts of Illinois, pollution has become critically severe only in the last few years, whereas other factors have been operative for a century or more.

The construction of dams to create mainstream impoundments holds sixth rank as a negative factor and is responsible for the decimation of four species of riffle-inhabiting fishes. The flowing stream consists of alternating riffles and pools. Riffles may flow over bedrock, boulders, rubble, gravel, or sand, and each bottom type comprises a distinctive habitat. Pools also may have different habitats, depending on the type of substrate and current. When a stream is impounded, riffles are eliminated and the bottom of the reservoir is rather quickly covered with silt, resulting in only one type of habitat. The richness of the fish fauna is directly related to the number of different habitats available. Dams also block natural migration and the dispersal of fishes.

The cutting of marginal trees and other vegetation that afford shade, coupled with a reduced flow of cold springs and low water levels during summer droughts, have resulted in higher water temperatures now than formerly. No data on past stream temperatures are available, but elevated temperatures offer the most likely explanation for the disappearance of the northern pike in streams of western Union County, where it occurred prior to 1900.

No single factor can be identified as the probable cause for the extirpation in Illinois of the stargazing darter, which once was found in the lower Wabash River. The decimation of the orangespotted sunfish, a species rather tolerant of silt and some pollution, is inexplicable.

So-called channel improvement through dredging and stream straightening destroys habitats over extensive stretches of streams, but by itself it cannot be regarded as the principal cause for the decimation of any native fish.

The following summary lists the factors primarily responsible for the extirpation of eight, and the decimation of 60 native species of Illinois fish (Table 4-11).

TABLE 4-11. SUMMARY OF FACTORS RESPONSIBLE FOR THE EXTIRPATION AND DECIMATION OF SOME ILLINOIS FISH

	Number of species extirpated	Number of species decimated
Silt	2	14
Drainage	0	13
Desiccation during drought	0	12
Species interaction	2	7
Pollution	2	5
Dams and impoundments	0	4
Temperature	0	1
Unknown causes	2	4
Total	8	60

4.3.2.3 Factors Which May Be Responsible for the Decline of Avian Raptor

The 1960 decline of the barn owl, saw-whet owl, and loggerhead shrike could easily be attributed to pollution of food webs due to a pesticide, herbicide, or other man-made compounds. The precedent is the decline of other raptorial species which has been linked with the use of the pesticide dichlorodiphenyltrichloroethane (DDT) (41). The raptors are especially susceptible to the adverse effects of lipid-soluble pollutants, since their diet is high in animal fat and enhances bioaccumulation (41). This bioaccumulation could allow the level of these pollutants to increase to toxic levels in raptors, while insectivorous and/or herbivorous species would be unaffected (since most insects are killed before they can bioaccumulate an insecticide). In the 1960s, DDT was being replaced by other insecticides.

One of these compounds, or a new herbicide or other compound, could be responsible for the decline of the raptors.

4.3.2.4 Protective Measures Taken (40)

The Illinois Department of Transportation commissioned the Illinois Bureau of Environmental Science to prepare a report on rare and endangered species in Illinois. The chief purpose of this report was to provide readily available information to the Districts and Bureaus of the Illinois Department of Transportation for use in future transportation planning. It is to be hoped that ecologically sensitive areas will be investigated and avoided in the process of planning highways and other transportation developments.

Several legal measures have been taken to reduce the wanton destruction of endangered species. The habitat of several species has been acquired by Illinois and improved to favor that species. Other known land areas with other endangered species are being considered for acquisition. Lists, such as in Appendix Table A-IV-21, have been prepared to identify these species.

4.3.3 Agroecosystems

White County is an agricultural county, attractive by standards applicable to a general farming landscape. Although picturesque in some areas, the potential visual appeal of the county is occasionally downgraded by oil field equipment and associated saltwater damage.

The preliminary report for 1976 of the Illinois Crop Reporting Service (31) shows White County with 38,242 ha devoted to corn harvested for grain with a yield of 7.51 m^3/ha or 287,000 m^3. An additional 200 ha was devoted to corn harvested for all other purposes. This represents an increase in the area used for corn, the yield per hectare, and the total harvest from 1975. This same report has 30,000 ha of White County devoted to soybeans with an average yield of 2 m^3/ha. The hectares of White County, yield per hectare, and total yield of soybeans used for beans are down from the 1975 figures. In 1976, 18,000 ha of White County was used for wheat production with a yield of 3.32 m^3/ha. These figures are increased over the 1975 totals. In White County in 1976, 100 ha was devoted to oats with an average yield of 3.66 m^3/ha; these numbers for oats represent an increase over the 1976 figures. The 1975 figures for barley are 61 ha with an average yield of 3.66 m^3/ha and the 1975 numbers for rye are 40 ha with an average yield of 8.90 m^3/ha.

In White County in 1976, 2600 ha was devoted to the production of hay with an average yield of 5.11 Mg/ha; these same numbers apply to the 1975 harvest. The land devoted to the production of sorghum was 910 ha in 1976 with an average yield of 5.30 m^3/ha; the land devoted to sorghum was up from the 1975 figure of 850 ha, but the yield per ha decreased from 6.00 m^3/ha.

The dollar value of various grain and hay crops in White County for the years 1975 and 1976 is as shown in Table 4-12.

The value of all cattle in White County in 1977 was about $4.5 million. This value represents a slight increase over the 1976 value. In 1977 there were 6,800 head of beef cattle and 300 milk cows in White County. The White County milk cows produced 1,360 Mg of milk. In 1976, there were 36,700 hogs in White County. Fifty-one thousand nine

TABLE 4-12. DOLLAR VALUE OF VARIOUS GRAIN AND HAY CROPS IN WHITE COUNTY, ILLINOIS, 1975 AND 1976

Crop	1975 $ value	1976 $ value
Corn	$17,931,500	$18,932,000
Soybeans	12,976,400	15,439,700
Wheat	4,029,000	5,136,100
Oats	10,400	17,100
Barley	13,900	
Rye	5,500	
Hay	590,300	674,500

hundred new hogs were saved from 7,200 sows farrowed. In 1977, 600 stock sheep were present. In 1976 in White County, 13,100 layers laid $3x10^6$ eggs.

4.3.4 Natural Areas Near White County

4.3.4.1 Beall's Woods Natural Preserve, Wabash County, Illinois (43,43,44)

Beall's Woods is located on the Wabash River 8 km south of Mt. Carmel; it is 120 ha in size and consists of bottomlands and a Southern uplands section.

Beall's Woods is a unique, near-virgin forest with a great variety of trees. Eleven kinds of oaks, and six kinds of hickories are among the 340 plant species present. It includes approximately a half-section of land on both sides of Coffee Creek and Sugar Creek at their confluence with each other and with the Wabash River. Outcrops of sandstone and coal are present.

Eight forest types can be recognized; four on the upland and four on the floodplain periodically inundated by the Wabash River. White oak predominates on the upland. Several tree species important in the lower Mississippi River bottomlands are found on the floodplain. Trees 0.9 to 1.2 meters in diameter are relatively common, particularly on the floodplain.

On the moist higher ground a flower display may be seen from April to May consisting of yellow fumewort, violets, bloodroot, Dutchman's breeches, and toothwort. As the spring flood waters retreat in late April, first spring cress and then swamp buttercup are conspicuous in the bottomlands. In May, the upland spring herbs disappear, while a heavy herbaceous cover develops in the bottomland, characterized by single-species dominance of local areas. Aster species, and flowering butterweed (Senecio sp.) are important, as is poison ivy. During June and July the creek floods up 1 to 2 meters following rains. Some large trees on the floodplains are found uprooted during these periods. Down timber has also been observed on the upland in early spring. New herbs are observed flowering in September with progressive drying of the creek beds.

A number of species, approximately 60 trees, 15 shrubs, 22 vines, 5 ferns, and 238 herbs, or a total of 340 species occur on less than 0.65 km^2. Tree species characteristic of the Mississippi River bottomlands further south, but not usual for this latitude (38°22') in Illinois include: persimmon, overcup oak, basket oak, Shumard's red oak, cherrybark oak, sweet gum, and sugarberry.

White oak is the predominant tree on the upland areas. Associated black oaks are also present. Shagbark, pig nut, and small-fruited hickories are the more usual species on the upland. Variants occupying moist zones of the relatively flat uplands include tulip tree and sugar maple. A red oak-basswood forest type, commonly found on relatively steep slopes above streams in northern and central Illinois, is found here. Basswood is reproducing vigorously with many head-high saplings present. This contrasts with the southern part of Illinois, where basswood is virtually absent and the red oak-beech-black gum type occurs on such slopes.

The vegetation on the areas lying below the 122 m contour may be divided into four additional forest types. That closest to the creek, occupying the floodplain at approximately the 117 m contour, is characterized by large trees. Silver maple, pecan, and sycamore are conspicuous, with local basket oak. Scattered river birch and cottonwood are found. In the southeastern area, lying only slightly higher in elevation, large sweet gum trees, to 1.2 meters diameter at breast height (DBH), are important. Hackberry is relatively common in this area. The lowland oak type is important in several parts of the floodplain extending from roughly the 117 m contour to about the 122 m contour where it intergrades with the other oak types. The lower-lying areas have trees of the previously listed floodplain types with oil marks visible on the trunks more than head high. An approximate gradient of oak species, in relation to decreasing amounts of flooding, is the pin oak-burr and swamp white oak-cherrybark and Shumard's red oak. Individuals of pin, burr, and Shumard measure over 1.2 m DBH. Shell-bark hickory is found locally in this type.

Adjacent to Coffee Creek, above the 116 m contour in the narrower valley of its upper reaches, is a hackberry-elm type.

This area has been described here in detail since it most likely represents what the flora of the White County area would be like without human disturbance.

The Beall's Woods area is owned and managed by the Department of Conservation. Five foot trails and one footbridge are the only developments in the preserve.

4.3.4.2 Big Creek Woods Memorial Nature Preserve, Richland County, Illinois (44)

Big Creek Memorial Nature Preserve is located 4 km south of Olney on Route 130. It is 16 ha in size and occurs in the Mt. Vernon Hill Country Section of the Southern Till and Plain Division. Developed nature trails exist in the preserve.

The area supports dry, mesic, and wet second-growth forests on a gently dissected till plain and on the floodplain of Big Creek. White oak (*Quercus alba* L.) and sugar maple (*Acer saccharum* Marsh.) predominate on upland sites, with blackberry (*Celtis occidentalis* L.) and sycamore (*Platanus occidentalis* L.) being common in ravines. Pin oaks (*Quercus palustris* Muenchh.) occur along the creek. The creek forms a permanent habitat for native fish; small outcrops of shale occur along the creek's banks.

The area is owned by the Nature Conservancy and leased to Olney Central College for management. Access is by permit from the Biology Department of the college.

4.3.4.3 Lusk Creek Canyon Nature Preserve, Pope County, Illinois (42)

Lusk Creek Canyon is 6 km northeast of Eddyville. It comprises 50 ha of the Greater Shawnee Hills Section of the Shawnee Hills Division. The principal feature is a deep gorge eroded through Pennsylvanian sandstone by Lusk Creek. The gorge is very scenic and supports relict populations of northern plants along its north-facing walls. Many rare plants including the hay-scented fern and at least 13 kinds of native orchid occur here. The valley forests are dominated by sugar maple (*Acer saccharum* Marsh.), beech tree (*Fagus grandifolia*), and tulip-tree (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.) and red oak (*Quercus rubra* L.) predominate on the slopes. Blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), and scarlet oak (*Quercus coccinea*) occupy the bluff tops. The area includes a stone wall built by prehistoric Indians. Lusk Creek provides an unpolluted aquatic environment and is owned by the Illinois Department of Conservation. Access is presently via foot trails over Shawnee National Forest land and private properties. Nature trails have been developed.

4.3.4.4 Natural Areas of Gibson County, Indiana (45)

Hemmer Woods is a dedicated state nature preserve. The area is in the Wabash Lowland Physiographic Province. It is dominated by old second growth and old growth sweet gum, tulip poplar, red maple, and elm in the lowlands, and by white, black and red oak and several species of hickories in the uplands. The state champion sweet gum is found here.

Cane Ridge was a terrestrial and aquatic biological area. This area was described in *Natural Areas in Indiana*, but has since been cleared and excavated for a cooling lake for the Gibson County electrical generating plant.

4.3.4.5 Natural Areas of Posey County, Indiana (45)

Mumford Hills Natural Area is located in Posey and Gibson Counties. It has an upland forest of sugar maple, tulip poplar, basswood and mixed oaks. Bottomland forest consists of red and silver maple, burr oak, Shumard oak, shellback hickory, green ash, and pecan. Quite a few very large trees can be found.

Half-Moon Pond Woods is a terrestrial and aquatic biological area. It is one of the deeper oxbow lakes in the lower Wabash Valley. Young and mature second growth trees can be found. Southern flora includes post oak, swamp privet, and false aloe.

The Hovey Lake State Fish and Game Area reportedly contains southern flora and fauna considered extremely rare in Indiana. It once contained the largest cypress stand in the state before being flooded by the Uniontown locks and dam. While the present status of this area is unknown, it is likely that high quality vegetation may still exist in parts of the area.

Goose Pond Cypress Slough is a large stand of cypress trees with other representatives of southern flora.

Grays Woods and Cypress Slough was once a high quality natural area including cypress slough, southern bottomland, and upland forest. It has been heavily disturbed due to logging and the drilling of oil wells.

Old Dam - New Harmony Cutoff consists of a natural rock ledge and rapids located in the Wabash River. It has type location for two fish and four turtles; these include black crappie, grass pike, spiny soft shell turtle, smooth soft shell turtle, red eared turtle, and false map turtle. The eastern mud turtle (Kinosternon subrubrum subrubrum) has also been found on this site, and will probably be listed as endangered or threatened in Indiana.

4.3.4.6 Natural Areas of Knox County, Indiana (45)

Little Cypress Swamp contains state champion cypress trees and southern bottomland flora; however, much of this large swamp has been cleared.

The Brushy and Half-Moon Ponds area is described as a shrub swamp and oxbow pond. Many species of waterfowl and even coyotes can be found here.

4.4 Site Selection Factors Specific to White County

Earlier in this section, an attempt was made to summarize generic environmental issues important to the siting and construction of the SRC facility. Following that summary, the environmental setting of White County was described in general terms relative to existing biotic and abiotic features. Using this information, an evaluation will now be made of those site factors, favorable or unfavorable, that might play a major role in the future development of the SRC technology in the White County area.

4.4.1 Favorable Siting Factors

The National Coal Policy Project (NCPP) Task Force on Mining has recommended that coal development technologies be concentrated in the Illinois Basin and eastern states such as West Virginia and Pennsylvania, and in the Gillette/Decker area of Montana and Wyoming (i.e., the Powder River coal region) (46). The following principles were developed by the NCPP in formulating their recommendations:

- Energy resources must be allocated in an economically efficient manner.
- The competitive marketplace encourages energy conservation and investment in energy-conserving devices.
- The competitive market encourages consumers to demand environmentally sound energy systems, particularly in non-attainment areas, on the premise that control technologies will be used to protect the air, water, and land environment.
- Where the operation of the market will not provide proper environmental protection, the government should do so by incorporating the costs of environmental damage into the price of energy through regulation.
- The federal government should promote research and development in the use of coal; this includes basic research relating to new technologies based on coal.
- Develop policies designed to reduce to a minimum the amount of government involvement in energy markets, and to protect important public values over those that encourage greater government involvement.

The NCPP (46) issued several consensus policy statements and recommendations through several task forces composed of leading environmental and industrial (coal) representatives. These statements and recommendations were arrived at by use of an approach referred to as the Rule of Reason, rather than the traditional adversary approach (46).

The findings of the Task Forces on Mining, Coal, Transportation, Energy Pricing, and Emission Charges are summarized elsewhere (46). Brief summaries of the Task Forces on Air Pollution, and Fuel Utilization and Conservation are as follows (46):

4.4.1.1 Task Force on Air Pollution

Site selection for coal-related activities should be consistent with social, economic, and engineering practices, and should allow location in remote areas where substantial justification exists. The task force recommended that state governments should adopt siting statutes that require long-range planning for the construction of energy facilities, provide a single, streamlined application procedure (i.e., for permits and approvals), require consideration of all relevant environmental and socioeconomic factors, and provide for full citizen participation (including dollar grants) in the siting decision process.

In order to promote equitable air quality modeling, it was recommended that the EPA, in collaboration with citizen groups, require and develop standardized air quality models that will correctly predict the amount of pollutants. Thus, new ambient air quality standards should be promulgated by EPA as soon as a significant risk of harm to human health or welfare is established. To encourage the expansion of the level of knowledge on the effects of carbon dioxide emissions on climate, it was recommended that such studies be given high research priority both in time and resources.

4.4.1.2 Task Force on Fuel Utilization (46)

The development of new technologies for the use of coal was considered but no specific recommendations were made because the Task Force felt that the arguments for or against new coal technologies were highly complex and usually involved proprietary information. However, the Task Force felt that the government should fund and encourage basic and applied research early in the development of new coal technologies. As new technologies are developed to a demonstration (or higher) status, private enterprise should finance the commercialization of the preferred new technologies. Both environmental and economic objectives should be considered. Thus, a potentially economically attractive technology should be considered only if there are good prospects for controlling environmental impacts (46).

According to a report from the Argonne National Laboratory, only the states of Illinois, Indiana, Missouri, North Dakota, and Ohio, among the 14 midwestern states studied, exhibited a favorable coincidence of usable water and coal resources. The former U.S. Bureau of Mines classification of coal reserve regions places Illinois, Indiana, and Western Kentucky in the Eastern Interior; Missouri, Arkansas, Iowa, Kansas, and Oklahoma in the Western Interior; North Dakota, South Dakota, and Montana in the Northern Great Plains; and Ohio, Pennsylvania, and West Virginia in the Appalachian coal regions. States having the highest potential for coal conversion development are reported to include Ohio, Pennsylvania, West Virginia, Kentucky, Illinois, New Mexico, Montana, Wyoming, and North Dakota (47), as shown in Table 4-13 and Figure 4-10. Thus, the counties of Hamilton,

TABLE 4-13. STATES HAVING HIGH COAL RESERVES (47)

Area Number	State and County	Type of Reserve Base
1	Ohio (Jefferson, Harrison, Belmont) Pennsylvania (Washington, Greene) West Virginia (Marshall, Marion, Monongalia)	Deep
2	Kentucky (Hopkins, Muhlenberg, Webster, Union, Henderson) Illinois (Hamilton, Williamson, Saline, Gallatin)	Strip-deep
3	Illinois (St. Clair, Washington, Perry, Madison, Sangamon, Christian, Macoupin, Montgomery, Bond)	Deep-strip
4	Illinois (Vermilion, Edgar)	Strip-deep
5	Illinois (Knox, Fulton, Peoria)	Strip
6	New Mexico (San Juan)	Do
7	Montana (Big Horn, Rosebud, Powder River, Custer) Wyoming (Campbell, Johnson)	Do
8	North Dakota (Dunn, Mercer)	Do

Williamson, Saline, and Gallatin (Area 2 of Figure 4-10) in Illinois have large coal reserves. Only Saline and Williamson County in southeastern Illinois have surface-mineable coal. White County, on the other hand, has about half as much underground mineable coal as Gallatin and Hamilton (47). One advantage accruing to White County as a potential SRC site is that it is located close to a useable water supply and is adjacent to mineable underground coal in Hamilton (to the west) and Gallatin County (to the south). The surface mineable coals of Saline and Williamson Counties, however, are about 80 km from the potential SRC site located in the northeastern corner of White County.

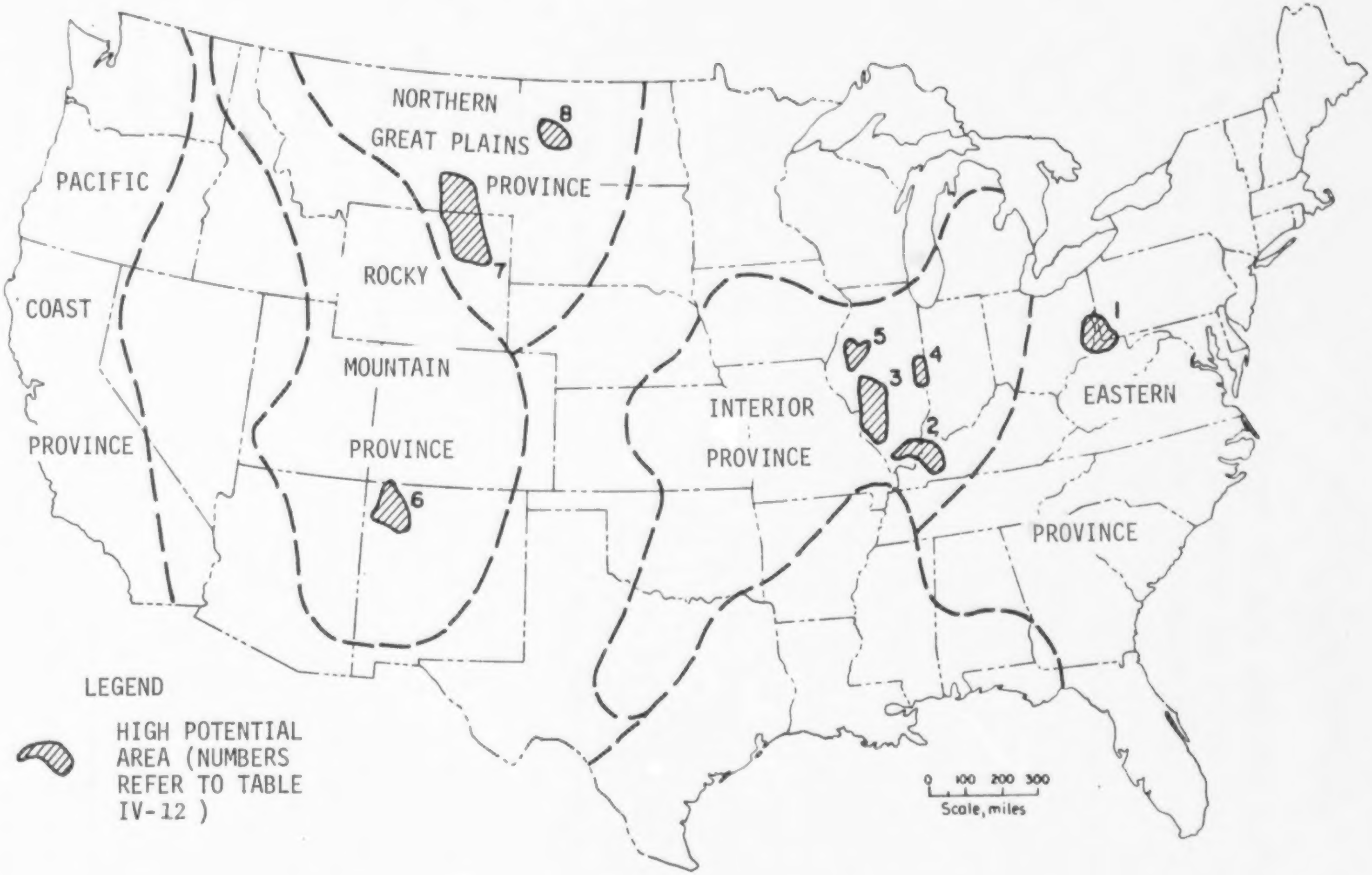

NORTHERN
GREAT PLAINS
PROVINCE
8
PACIFIC
COAST
PROVINCE
ROCKY
MOUNTAIN
PROVINCE
7
6
INTERIOR
PROVINCE
5
4
3
2
1
EASTERN
PROVINCE
LEGEND
HIGH POTENTIAL AREA (NUMBERS REFER TO TABLE IV-12)
0 100 200 300
Scale, miles

Figure 4-10. Areas of high potential for coal conversion development (47)

4.4.2 Constraints to Siting

After one full year of study, the National Coal Policy Project (46) could not reach agreement on the key issue of the prevention of significant deterioration of ambient air quality, vis-a-vis the 1977 amendments to the Clean Air Act. With reference to the southeastern Illinois area, it is likely that the relative flatness of the terrain plus the rather favorable meteorological conditions for pollutant dispersion throughout the area, should greatly minimize ambient air pollution as future energy technologies expand in the area. However, air pollutants such as CO_2 and particulates that are readily dispersed in this flat terrain can be transported to downwind areas to the north and east of the area, including the northeastern United States. The relative importance of this factor depends partly upon the successful application of the best available control technology for the six criteria air pollutants, and also upon the early identification of sites that are environmentally unsuitable for the development of the synfuels technology.

Other potential constraints to the siting of coal conversion facilities in southeastern Illinois include: potential risks from earthquakes (i.e., fault and failure impacts); water allocation conflicts between consumptive instream users; disruption of aquifers as a result of coal extraction; accelerated decline of railroads and highways due to mounting maintenance costs; disruption of non-consumptive instream water uses; impact of the "offset principle" relative to projected gaseous emissions from sources other than SRC; the effect of existing oil well regulations on new mine development; constraints stemming from the prime farmland concept of the USDA, flood-prone areas, and costs of pumping water. Discussion will be limited for the present to seismic risks and the last four items of the series.

The remaining items can be discussed satisfactorily after the completion of detailed evaluations on a site-by-site basis.

4.4.2.1 Potential Risks for Seismic Events

The regional faulting areas of southeastern Illinois are shown in Figure 4-11 for the Fairfield Basin. Three major fault systems are recognized, as follows:

- Shawneetown - Rough Creek Fault Zone
- Cottage Grove Zone
- Wabash Valley Fault System.

The Wabash Valley Fault System contains a series of high-angle faults that extend to the north from the Cottage Grove and Shawneetown-Rough Creek Fault Zones through Gallatin, Saline, White, Wabash, and Edwards Counties along the Wabash River basin (48). According to Heigold (48) the magnetic highs, shown in Figure 4-12, are much sharper and more definitive than the gravity highs shown in Figure 4-13. Based on the size and regional extent of these anomalies, Heigold (48) concluded that their source was in the crust or upper mantle of the earth. Thus, faulting appears to have occurred in both the crust and upper mantle. All observed earthquakes have occurred in the crust or mantle of the earth. The major immediate cause of earthquakes is generally believed to arise from the gradual accumulation of large stresses in blocks of rock that produce faulting, or the relative movement of blocks of rock along a fracture surface. This belief is correlated with the fact that many earthquakes occur in known fault areas, and their greatest intensity occurs in elongated strips along the intersection

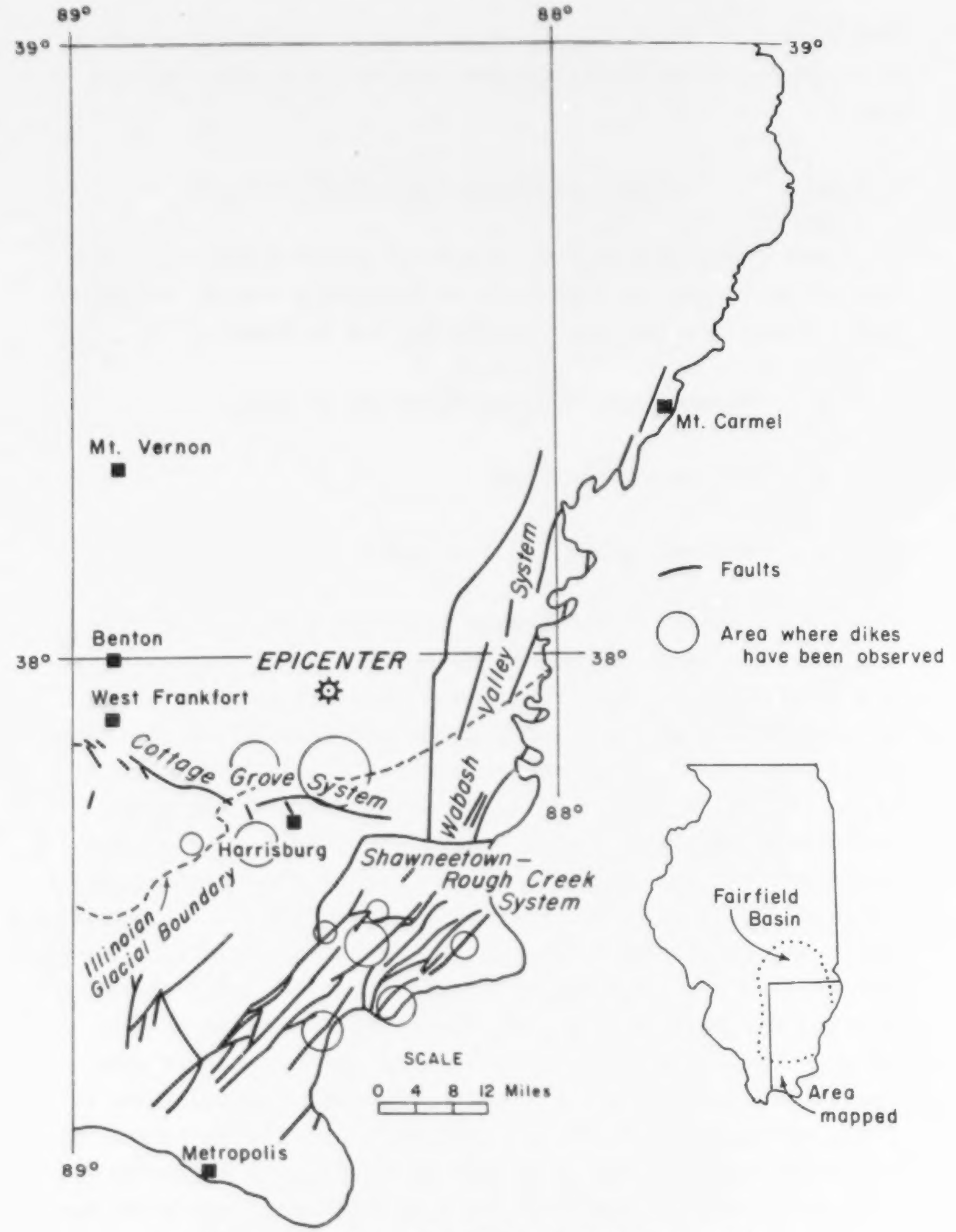

89°
88°
39°
39°
Mt. Carmel
Mt. Vernon
Faults
Area where dikes have been observed
Benton
38°
EPICENTER
38°
West Frankfort
Cottage Grove System
Wabash Valley System
88°
Harrisburg
Shawneetown – Rough Creek System
Illinoian Glacial Boundary
Fairfield Basin
SCALE
0 4 8 12 Miles
Area mapped
89°
Metropolis

Figure 4-11. Regional faulting map of Southeastern Illinois (48)

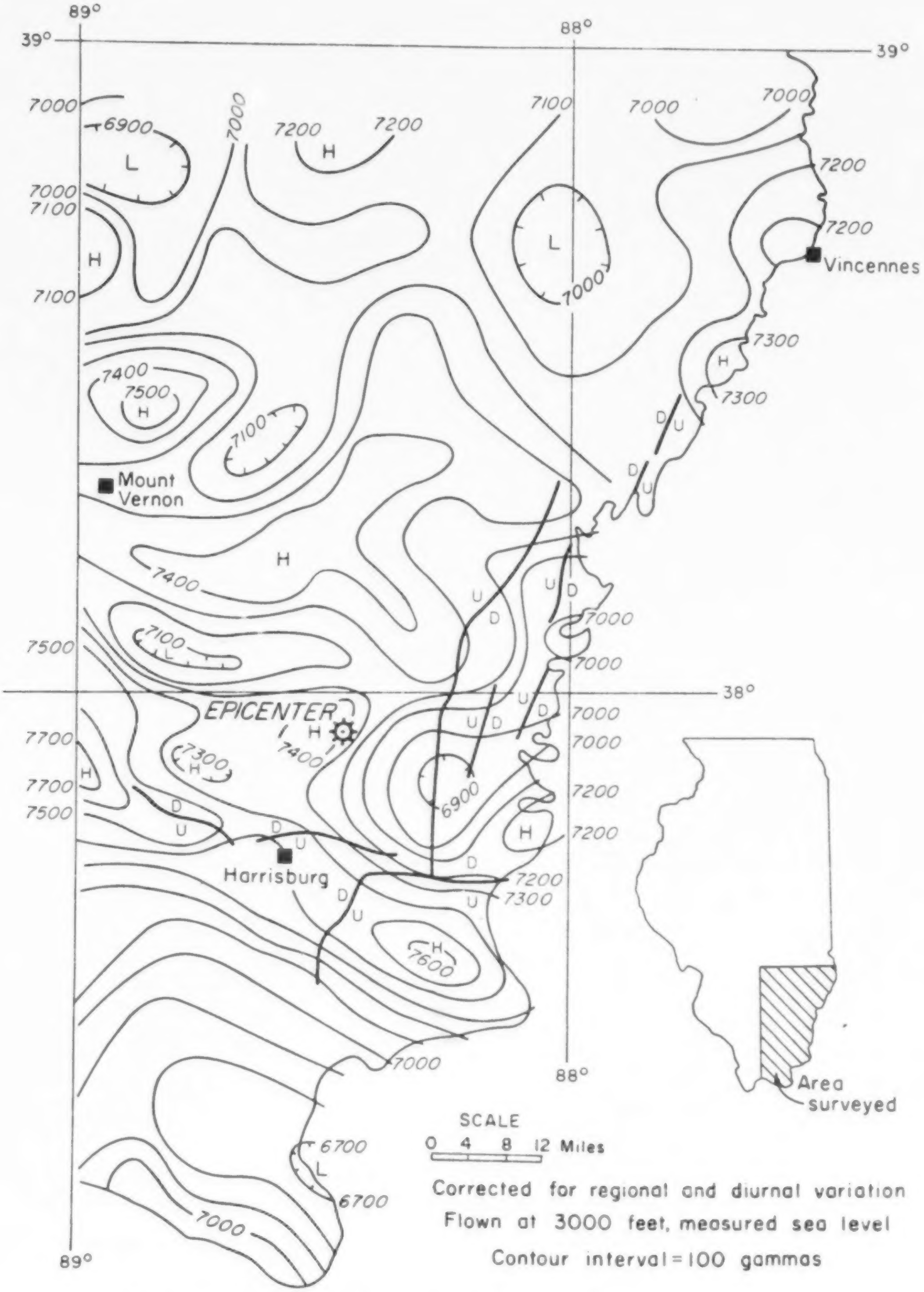
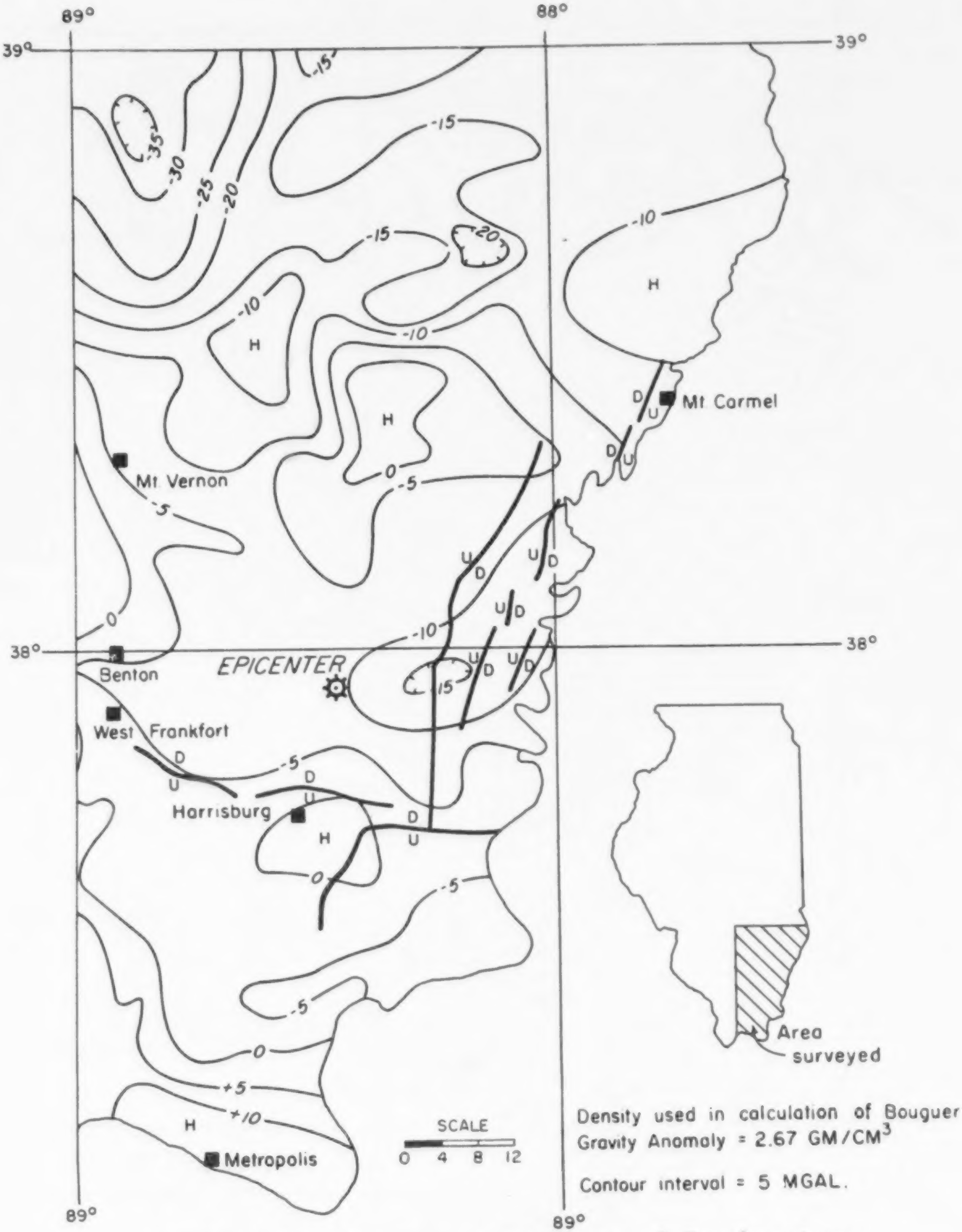

89°
88°
39°
39°
7000
6900
L
7000
7200
H
7200
7100
7000
7000
7000
7100
H
7100
L
7000
7200
7200
Vincennes
7300
H
7300
7400
7500
H
7100
Mount Vernon
D
U
D
U
H
7400
U
D
U
D
7000
7100
L
7500
7000
38°
EPICENTER
H
7400
U
D
7000
7000
7700
7300
H
H
7700
6900
7200
7500
D
U
D
U
H
7200
Harrisburg
D
7200
D
U
U
7300
H
7600
7000
88°
Area surveyed
SCALE
0 4 8 12 Miles
6700
L
6700
7000
Corrected for regional and diurnal variation
Flown at 3000 feet, measured sea level
Contour interval = 100 gammas
89°

Figure 4-12. Total field aeromagnetic map of Southeastern Illinois (48)


89°
88°
39°
39°
38°
38°
89°
89°
-35
-30
-25
-20
-15
-15
-15
-20
-10
-10
-10
-10
H
H
H
H
H
H
0
-5
-5
-5
0
-10
-15
-5
0
-5
-5
0
+5
+10
Mt. Carmel
Mt. Vernon
Benton
EPICENTER
West Frankfort
Harrisburg
Metropolis
D
U
SCALE
0 4 8 12
Area surveyed

Density used in calculation of Bouguer Gravity Anomaly = 2.67 GM/CM^3

Contour interval = 5 MGAL.

Figure 4-13. Bouguer gravity map of Southeastern Illinois (48)

of the fault plane with the surface of the earth (48). The duration of an earthquake will be longer than the relative movement of blocks of rock (faulting) along a fracture surface. According to Heigold (48), the duration of ground motion (earth-shaking time) is proportional to the distance from the fault. Thus, near the epicenter of the quake, the earth-shaking time may range from a few seconds to several minutes (48). Present evidence suggests that the number of earthquakes and their associated energy intensity decreases with the depth of focus. Some geologists consider that the Wabash and Ohio Valley systems of southern Illinois may be controlled by fault activity of rather old age.

4.4.2.1.1 Earthquakes in Southern Illinois

The depth of focus of the November 9, 1968, earthquake in southern Illinois was about 19 km, with a magnitude of 5.5 on the Richter scale. Thus, the 1968 quake was focused within the earth's crust which, for that area of Illinois, has a thickness of 35 km (48). As shown in Figure 4-11, the epicenter of the 1968 quake was located at the extreme end of the Fairfield Basin. Several triggering mechanisms are considered to apply to southern Illinois, as follows (48):

- Crustal rebound from unloading of glacial ice
- Crustal sinking due to recent deposition in the Mississippi Embayment
- Sudden changes in barometric pressure
- Changes in surface-water loads
- Earth tides.

Present evidence shows that ever since the catastrophic New Madrid earthquake of 1811 (intensity 8.1 on the Richter scale), no earthquakes have occurred in southern Illinois having intensities greater than 6.2 (Richter scale). This intensity falls at the lower limit of serious damage to man-made structures. In the 1968 earthquake, major damage was reported at the epicenter. Areas to the east and south reported minor damage such as cracking of plaster walls, leakage in a concrete wall seal in the air shaft of the Peabody Coal underground mine No. 90 (Gallatin County) at a depth of about 24 meters, and falling bricks from a parapet wall in Norris City (White County) (48). The Illinois Geological Survey conducted an investigation of the overall damage done by the 1968 earthquake and concluded that, with the exception of a few structures located close to the epicenter, only minor damage occurred (48). The Illinois State Water Survey evaluated the effects on groundwater levels and levels in water wells, and concluded that no changes had occurred in these water levels. This finding was in sharp contrast to the 1964 Alaskan earthquake that showed pronounced changes in groundwater levels (48).

4.4.2.1.2 Structural Engineering Countermeasures

In 1974, the Applied Technology Council (ATC) evaluated building design procedures for 11 building types (see Table 4-14) for an area near Los Angeles that would ensure protection to buildings, given the response spectra representative of damage-threshold and collapse-threshold earthquake ground motions at a given site (49). The damage-threshold spectrum, representative of ground motions having a low probability of occurrence, established the seismic force levels for member design. The collapse-threshold spectrum, representative of ground motions with a very low probability of occurrence, established the structural deformations

TABLE 4-14. COST CONSEQUENCES OF DESIGN METHOD (49)

Bldg. No.	Stories: Material	Construction Cost	Addition to Cost	Percent Increase	% Increase in Engineering Cost
2	19:Steel	11,000,000	12,000	0.1%	5%
4	14:Concrete	4,000,000	86,601	2.2%	20%
3	10:Concrete	3,500,000	50,333	1.4%	5%
8	9:Concrete	3,800,000	27,654	0.7%	15%
5	6:Concrete	1,400,000	55,452	3.9%	5%
1	5:Concrete	6,670,000	237,364	3.5%	27%
7	3:Masonry Wall, Metal Diaph.	534,000	44,371	8.3%	10%
6	2:Steel	1,050,000	15,019	1.43%	30%
10	2:Steel	2,400,000	9,049	0.38%	15%
9	1:Tilt-up Wall, Plywood Diaph.	120,200	11,723	9.7%	30%
11	1:Masonry Wall, Plywood Diaph.	1,113,000	11,860	1.0%	15%

required for stability analysis and evaluation of member ductility demands. The life span of building design was set at 70 years (49).

Construction costs consequences of the design method are shown in Table 4-14. Construction cost (Column 3) is defined as the original cost to build each type of building in Column one. Addition to cost (Column 4) is extra cost of items required by the design method beyond requirements of the 1973 Uniform Building Code. Thus, additional costs of upgrading to the project criteria varied from 0.1 to 10 percent of the total cost of a building. Increased engineering costs needed to design according to project criteria varied from 5 to 30 percent of the costs stemming from use of the Uniform Building Code (49).

With reference to additional architectural changes required in the form of additional walls, it was found necessary to add extra walls to Buildings 7 and 9 to control diaphragm stresses and deformations (49).

The extent to which these ATC data may be relevant to the construction strategies for synfuel plants in seismic risk areas has not been established. For example, additional architectural costs would likely occur from the standpoint of providing worker safety around conveyors, storage areas, and reactors in the event of an earthquake during the projected 25-year lifespan of the SRC facility.

4.4.2.2 Existing Regulations Pertaining to Oil Wells

According to Smith and Stall (8), a substantial percentage of the in-place coal resources lie above oil pools and are considered unmineable by current mining practices. Federal mining laws prohibit mining within an area of about 91 meters in diameter around each well, unless the wells are adequately plugged and permission to mine obtained from federal authorities. Smith and Stall (8) also reported that the 100,000 test holes (i.e., for oil or gas) within Illinois have been properly recorded by location and numbers on maps. New methods of plugging abandoned oil wells have been developed that will permit mining without leaving the larger barrier pillar around each well.

4.4.2.3 Prime Farmlands of White County

Prime farmland of an area is defined as land (i.e., soil associations) considered best suited to the production of food, forage, fiber, and oilseed crops, based on soil characteristics that include soil fertility, soil moisture, and other physical criteria. The proper combination of these criteria, when applied to specific soils so as to produce sustained high yields of crops, can result in such soils being designated as prime farmland. According to Bennet (50) the prime and nonprime farmlands of White County include the following soil types and designations:

TABLE 4-15. SOIL TYPES AND DESIGNATIONS: WHITE COUNTY FARMLANDS

Soil type	Designation
Alford, Hoyleton, Reesville, Camden	Soils with less than 6% slopes are prime farmland
Iva, Hosmer, Ava, Bluford	Soils with less than 5% slopes are prime farmland
Alvin, Lamont	Soils with less than 8% slopes are prime farmland
Cisne, Ruark, Patton, Allison, Beaucoup, Tice	These soils are prime farmland regardless of slopes encountered
Bonnie, Belknap, Petrolia, Cape, Karnak	None of these soils is considered prime farmland since they are subject to flooding at least once every two years

4.4.2.4 Flood-Prone Areas (6)

About half of White County contains flood-prone sites. Construction in floodplain areas is regulated by the Illinois Department of Transportation (IDOT), whereby IDOT is authorized to establish a procedure for issuance of construction permits in defined floodplains.

Floodplain development is also controlled indirectly by a federal flood insurance program enacted under the National Flood Insurance Act of the Housing and Urban Development Act of 1968, Title XIII of PL 90-448. It was intended that this insurance program would be part of a unified national effort for the management of the nation's floodplains, eventually making flood insurance available nationwide. In order for a community to be considered for coverage, the program requires state and/or local assurances that efficient land use policies, as established by HUD criteria, be adopted and enforced to regulate land use, and future development in these areas. The program would provide insurance at subsidized rates on certain existing structures and their contents, but would serve as a deterrent to continued, unregulated construction in these flood-prone areas.

Flood-prone area maps are presently being prepared for White County that delineate areas subject to inundation during a 100-year flood. The areas subject to flooding can be divided into the following four categories: (1) floodway, (2) floodway fringe, (3) regulatory flood limit, and (4) standard project flood limit.

The regulatory floodway is that portion of the floodplain required to store and discharge flood waters without causing significant damaging or potentially damaging increases in flood heights and velocities. The IDOT regulations dictate that in those areas which are defined as the regulatory floodway, there can be no construction which would result in increased flood heights or velocities, or cause pollution, erosion, sedimentation, fire hazard, or other hazard or nuisances.

The areas designated as flood fringe are subject only to shallow inundation and low-velocity flows, and thus play a relatively insignificant role in storing and discharging flood flows (6).

A wide range of uses may be permitted in the flood fringe, provided that such uses are protected to include the regulatory flood protection elevation. Protection of construction to the regulatory flood protection elevation must, in most instances, be provided through landfill. However, other methods of floodplain development which cause no significant increase in stage or velocity may be permitted, if supported by adequate engineering data. Construction undertaken with a flood plain construction permit shall comply with the standard and special conditions of that permit.

Once an area has been filled or otherwise protected in compliance with an approved construction permit, subsequent construction within the protected area above the regulatory flood protection elevation may proceed without further permits, if all local requirements such as zoning and building permits are met (6).

With reference to the construction of the proposed SRC-II facility and its auxiliary units adjacent to flood prone areas, it appears that the relevant parameter is the depth of the site terrain below the level of the maximum probable flood (MPF) level (plus one foot) measured in feet. In order to avoid this danger, the relevant design approach is to build a levee (51). Informal estimates by Corps of Engineers indicate that a reasonably sized levee for this purpose might be 3.05 m wide at the top with a 2.5 to 1 ratio for the slopes, assuming average soil material (51). The dollar cost of constructing such a levee can be easily calculated; however, the ecological costs would have to be determined on a site-specific basis.

4.4.2.5 Water Pumping Costs

In arriving at an estimate of the comparative cost of obtaining the requisite amount of water for the proposed SRC-II plant and the auxiliary power plant, it appears that the State of New York's PSC curves could be quite useful (51). These curves show average costs as a function of distance from the water body and the height of pumping needed. An obvious tradeoff refers to the decision to pipe water from a stream vs. locating close to a stream, as would be applicable to the Wabash River area of White County. Another tradeoff refers to the use of cooling towers vs. cooling ponds for the auxiliary power plant.

4.5 Current Environmental Monitoring and Related Programs

Environmental monitoring involves the repetitive collection of data that will guide the formulation, and aid the implementation, of environmental management policies designed to protect human health and the integrity of aquatic and terrestrial ecosystems. Because data collection is very expensive, it is imperative that better inferences be made from fewer observations that are carefully collected, thus requiring more careful planning and the exercise of more quality assurance (52). The usefulness of much of the earlier environmental monitoring data is considered of questionable value, because of the use of non-uniform analytical methods and the lack of quality assurance (52). Environmental monitoring may be strictly physical, biological, ecological, or epidemiological, or combinations thereof, with reference to air and water quality, noise, radioactivity, and land use (including solid and hazardous waste disposal sites).

Several types of monitoring information are required to prevent the adverse effects of multimedia pollutants, as follows (53):

- Establish the relationship between exposure levels of pollutants and their resultant effects on the critical receptors.
- Understand the relationship of the total exposure to which the receptors are subjected and the sources of the respective pollutants.
- Ascertain the effectiveness of pollutant control technologies in maintaining exposure levels of the pollutants at an acceptable concentration in air, water, and land environments.

As of November 1977, the EPA requires all EPA monitoring systems and laboratories to participate in their quality assurance program. Policies and regulations requiring compliance with formal procedures are conditional for EPA acceptance of any monitoring data.

4.5.1 Types of Monitoring (52)

Three categories of monitoring activities are recognized: source monitoring, ambient monitoring, and effects (health/ecological) monitoring.

4.5.1.1 Source Monitoring

The discharges of left-over wastes from a production activity such as the SRC technology may be classified as point sources, nonpoint sources, and mobile sources.

4.5.1.1.1 Point Sources

Residual discharges to air, water, and land occur from stacks, outfalls, cooling towers, and the like. Most source monitoring is done by individual dischargers, generally through the National Pollutant Discharge Elimination System (NPDES). State agencies prepare and submit air emissions inventory data on the location and amount of air pollutants emitted to the EPA data bank known as the National Emissions Data System (NEDS). Managers of Air Quality Control Regions use these data to predict ambient air quality.

Inventories of point source effluents to waterways are developed along similar lines for use in the development of plans for waste treatment facilities, and to establish effluent limitations required to meet existing water quality standards.

New point source dischargers of air pollutants must meet New Source Performance Standards (NSPS) if the new plant or process is built and operated after regulations for that industry have been issued by EPA. State agencies may monitor various sources of air and water pollution to assure compliance with state standards and permit requirements.

4.5.1.1.2 Nonpoint Sources

Nonpoint sources of water pollutants that emanate from areas such as feed lots, mines, and construction sites, must have EPA/NPDES permits; these require the monitoring of residuals in runoff from these areas (52). Under the so-called 208 program of the Clean Water Act, most state and local agencies are conducting nonpoint source monitoring for sediment, nutrients, and various inorganic elements on selected watersheds. The U.S. Geological Survey (USGS) and the USDA conduct land use inventories which also provide information on sediment, nutrients, and other residuals in water.

4.5.1.1.3 Mobile Sources

Spills of toxic and other hazardous substances occurring during transport, along with motor vehicle emissions, are comprised in this group. Spills from trucks, railroads, and pipelines are monitored by the U.S. Department of Transportation (USDOT); those from barges and other water craft are monitored by the U. S. Coast Guard of USDOT.

4.5.1.2 Ambient Monitoring (52)

The levels of known pollutants in air, water, soil, and living organisms are measured by a great array of federal, state, and local agencies.

4.5.1.2.1 Air Monitoring

Most of the ambient air monitoring is done by state and local agencies. The SIPs developed by each state provide information on the number of monitoring stations, air pollutants to be monitored, and other details. These plans must meet the minimum assay requirements established by the EPA for the nation's 247 Air Quality Control Regions, in monitoring the six criteria air pollutants. The states collectively operate about 8,000 stations and report the data to the EPA National Aerometric Data Bank (NADB). These data can be retrieved through the EPA Storage and Retrieval of Aerometric Data (SAROAD) program. The EPA operates the 400-station National Air Surveillance Network (NASN) in cooperation with state and local agencies. The EPA also operates the 20-station Community Health Air Monitoring Program

(CHAMP), covering both the criteria and noncriteria air pollutants. In the St. Louis area, the EPA operates a 25-station area network known as the Regional Air Monitoring System (RAMS) for the study of the transportation and transformation of air pollutants. As of 1976, over 600 SO_2 monitoring stations were operated by several large industries. The extent to which local ambient levels of other air pollutants are monitored by industrial groups is not known (52).

4.5.1.2.2 Water Monitoring

The U.S. Geological Survey and the EPA have primary responsibility for water quality monitoring in the federal sector. A total of about 30,000 water quality monitoring stations are operated by the USGS and the states, some of which are operated through cooperative arrangements with the states (52). More than 40 states and the USGS report ambient water quality data to the EPA Storage and Retrieval for Water Quality Data (STORET) program.

Recently, the USGS established the National Stream Quality Accounting Network (NASQAN), and the EPA set up the National Water Quality Surveillance System (NWQSS). The NASQAN network will consist of 525 stations by 1979; these stations will collect information on stream flow and pollutant concentrations in a number of water resource regions. The EPA national surveillance system will determine the effects of agricultural or industrial activities on water quality (52).

As required by the Safe Drinking Water Act, most state and local agencies monitor and report to the EPA on drinking water quality. Presently, EPA monitors the levels of harmful organics in the drinking water of about 100 cities. Radionuclide levels in drinking water are monitored at 76 sites (52).

4.5.1.2.3 Monitoring of Plants, Animals, and Man

The U.S. Fish and Wildlife Service and a number of states measure levels of mercury, pesticides, and other pollutants in tissues of fish, birds, and small mammals. The U.S. Food and Drug Administration measures levels of pesticides and six heavy metals in 117 market basket items comprising the average diet of teenage males. The EPA, through its Human Tissue Monitoring Program, measures the levels of PCBs and 19 pesticides in human biopsy and autopsy samples (52).

4.5.1.3 Effects Monitoring

The effects of air, water, and land pollutants on plants, animals, and man are monitored largely by federal agencies; however, the State of Montana is now operating a project called the Montana Air Pollution Study (MAPS) to establish the correlation between levels of fluoride and criteria pollutants and human health in selected areas (54).

4.5.1.3.1 Human Health Effects

In late 1974, the National Institute of Environmental Health Sciences (NIEHS), building upon the seven-year EPA Community Health and Environmental Surveillance System (CHESS 1969-1975), launched a 10-year epidemiologic study of air pollutants and health (55). This study is designed to relate the effects of known exposure levels of air pollutants in the general environment to human chronic respiratory symptoms and changes in pulmonary function. Thus, simultaneous and continuous measurements will be made of SO_2, sulfates, mass respirable particulates, TSP, NO_2, and ozone in the general environment (as opposed to the workplace). Health effects will be assessed by using questionnaires on respiratory symptoms, and by performing lung function tests. Answers will be sought to the major issues of a threshold level of exposure below which no effect is detectable, and the role of sulfates in human health (55). Six U.S. communities, varying in pollution level from low (2), to moderate (2), to high (2) will be assessed. Environmental exposure will be monitored at three levels, each of increasing refinement, as follows: central station, indoor/outdoor, and personal monitoring. In addition to the portable personal monitor, a second monitor of the same type will be placed in the test person's residence (55). One unique feature of this study is that changes in lung function of children can be measured in the absence of such obscuring factors as smoking and occupational exposure. The cities involved in this study include: St. Louis, Missouri; Steubenville, Ohio; Watertown, Massachusetts; Kingston-Harriman, Tennessee; Portage, Wisconsin; and Topeka, Kansas (55).

Cancer morbidity surveys and cancer incidence surveys are operated by the National Cancer Institute (NCI). The cancer incidence survey, called the Surveillance Epidemiology and End Results (SEER) program covers 10 percent of the U.S. population. Annual estimates of occupational illness are obtained by the Bureau of Labor Statistics for OSHA (52).

Recently, the National Research Council (52) recommended that a cancer detection program be established, based on continuing surveillance of selected groups of people whose occupations expose them to high levels of potential carcinogens. Formidable problems would be expected to arise in the recruitment of a voluntary sample population, the establishment of standard protocols, and the use of compatible sampling and analysis techniques. However, estimates of body burdens could be used to evaluate levels of exposure to hazardous pollutants, to establish correlations between disease states and body burden, and to identify changes in body burdens of pollutants (52).

Alternatively, a well-designed system of occupational health statistics was suggested to identify those chemicals that demand further study. Another promising alternative is the monitoring of changes in mutation rates in human chromosomes. Thus, findings of increased mutation rates would provide a basis for regulation of anthropogenic mutagens. However, retrospective case studies would be needed to determine the causal agents (52).

4.5.1.3.2 Ecological Effects Monitoring

The EPA operated the National Eutrophication Survey (1972-1975) to study the effects of nitrates and phosphates in 800 lakes. The Agricultural Research Service of the U.S. Department of Agriculture is studying the effects of air pollutants and pesticides on crops. Other federal agencies that monitor ecological effects are as follows (52):

- U.S. Department of Energy - pollution from power plants
- TVA - effects of SO_2 on vegetation near power plants
- U.S. Fish and Wildlife Service - effects of air pollutants and pesticides on animals.

Currently, the EPA - Environmental Research Laboratories at Gulf Breeze, Florida; Narragansett, Rhode Island; Duluth, Minnesota; Corvallis, Oregon; Athens, Georgia; and Cincinnati, Ohio are engaged in assessing the ecological and health effects of a number of hazardous substances, some of which represent potential discharges from the SRC-II technology. Results to date are preliminary only and long-term studies are contemplated. Other assessments of pollutants resulting from coal conversion technologies are being made by the Environmental Sciences Division at the Oak Ridge National Laboratory of the U.S. Department of Energy.

4.5.2 Current Air Monitoring Programs

The EPA is reportedly planning to revise its reporting of ambient air quality monitoring and source emission data, because the agency's Standing Air Monitoring Work Group found data of unknown precision and accuracy along with deficiencies in analytical instrumentation (56). The study group also found that ambient criteria pollutant networks had too few or too many monitors, deficiencies in monitor siting, quality control, and methodology. In source monitoring, problems were found with quality control and methodology. There is a real need for comprehensive inventories, and for more point source monitoring by private industry. The existing state implementation plan (SIP) ambient monitoring regulations were judged insufficiently flexible for current SIP needs (56).

The U.S. Department of Energy METER program, started in 1976, currently is collecting data at four coal-fired facilities around the United States relative to the environmental effects of heat and moisture releases from natural-draft cooling towers, mechanical-draft cooling towers, and from cooling ponds. This program is an effort to establish once and for all whether heat and moisture releases from cooling facilities can affect local rainfall patterns within a 10-mile radius of the plants (57).

4.5.3 Individual Dischargers Monitoring Programs

Point source dischargers of chemical pollutants to navigable waters (essentially all streams) and to the ocean must, under the NPDES program, submit information to the EPA (or to a state having NPDES authority) concerning the location, amount, and chemical nature of the discharge. Dischargers of sediment from mine sites and from construction sites also must comply with the NPDES permit program.

Limitations of the NPDES program refer to the fact that there is no Federal quality control or certification program covering laboratories submitting assay results. No Federal programs exist that require an industry to monitor the process waste streams, and there are no programs to require an industry to assess the environmental effects of potentially hazardous wastes generated by various industrial processes (although some leading industries do so) (52). Because of these perceived limitations, the National Research Council (52) has recommended that, before a new process or technology is instituted, the applicable industry should identify the substances that will be discharged and assess their potential environmental effects.

4.5.4 Water Monitoring Programs in Illinois

The Illinois EPA (IEPA) has operated a statewide water quality sampling network of monitoring stations on the Ohio and Mississippi Rivers and their tributaries, including the Wabash and Little Wabash River Sub-basins for many years (58). Sampling stations considered basic to the network have received regular visits since 1958, when the water quality sampling program was started. The IEPA presently operates five monitoring stations along the Wabash River (two in White County), eight along the Little Wabash (three in White County), and three along Skillet Fork (two in White County).

Two stream sampling programs are implemented statewide by the IEPA, as follows (58):

- Water quality sampling to determine surface water quality
- Water pollution sampling to determine the degree of pollution resulting from specific industrial and municipal sewage works.

As of 1976, the most troublesome water pollutants in the White County area were total iron, copper, and manganese (58).

4.5.5 Air Monitoring Programs in Illinois

White County is located in Air Quality Control Region No. 74, but no air monitoring stations are presently located in the county. Of the four monitoring stations comprising the AQCR, one is located at Mt. Vernon, one at Carbondale, one at Marion, and one at Effingham, Illinois (15).

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5.0 ENVIRONMENTAL EFFECTS INFORMATION, WHITE COUNTY, ILLINOIS

5.1 Factors Affecting Environmental Distribution and/or Effects of Pollutants

5.1.1 Site-Related Factors

Abiotic features of atmospheric, soil, and hydrologic conditions at the SRC site influence the potential distribution and impact of pollutants. The following section discusses the importance of the site factors in regard to attenuation of pollutants. In order to make assessments of the rate and extent of dissipation it is necessary to have extensive information regarding the characteristics of the receiving media as well as the characteristics of contaminants in the discharge. Table 5-1 summarizes various parameters which must be taken into account in order to estimate the fate of a discharged pollutant. The focus of this section will be primarily to describe general dissipative mechanisms operating in each media, procedures for estimating dissipation rates, and specific White County conditions which affect the dilution and dispersion of contaminants. Where sufficient information is available on pollutant discharge levels and the site conditions, estimates may be made for the expected potential distribution and dissipation of contaminants.

5.1.1.1 Atmospheric Factors (2,3,4,5,6,7)

The first-order weather station closest to White County is located at the Evansville-Dress Regional Airport, approximately 48 km SE of Grayville. The data from this station will have to be used to determine the emission impacts of any synfuels facility to be sited in the White County area.

TABLE 5-1. PARAMETERS AFFECTING DILUTION AND DISPERSION OF CONTAMINANTS DISCHARGED TO AIR, WATER, OR LAND (1)

Air	Stack flow Stack temperature Stack height Weather conditions: windspeed, sunlight, temperature, pressure Site topography Characteristics of discharge Photochemical reaction kinetics
Water	Flow rate of receiving stream Turbulence of receiving stream Temperature of receiving stream pH of receiving stream Flow rate of discharge Location or design of outfall Temperature of discharge Characteristics of contaminants in discharge: solubility, reactivity, pH, biodegradability, sorption characteristics Site topography Climate: temperature, rainfall
Land	Soil characteristics: permeability, pH, cation exchange capacity, weathering, sodium absorption ratio Characteristics of contaminants: ionization, leachability, biodegradability Characteristics of bulk solid waste: surface-to-volume ratio, density Method of disposition Climate: temperature, rainfall

The 1977 Climatological Summary for this station can be found in Appendix Table A-V-1; this table shows that the prevailing wind direction is from the south. Strong cold winds sometimes blow from the north and northwest following cold frontal passages but as soon as the high pressure ridge moves by, moderation usually begins with the wind backing through the west and again into the south.

Rainfall and snowfall can "wash" pollutants out of the air and deposit them in streams, land areas, or in the oceans; this is especially true of pollutants attached to particulates. These pollutants may then become land and water pollutants. Pollution due to atmospheric washout is hard to quantify, even theoretically. The amount and distribution of precipitation available for washout is discussed in Chapter 4 of this report.

Wind speed is one of the most important factors in the dispersion of air pollution. Wind may cleanse a polluted atmosphere at a given location by moving masses of stagnant air away from the point of origin, preventing an accumulation of pollutants. It dilutes the concentration of a contaminant directly, and as it moves over rough terrain the resultant turbulent flow mixes the contaminant into a larger volume of air, further diluting it.

Horizontal wind speeds below 7.2 km per hour are generally considered to be conducive to pollution conditions. The weakest transport and dilution occur at low wind speeds; and the greatest thermal stability, which inhibits vertical motion, often occurs at wind speeds of less than 7.2 km per hour. Appendix Table A-V-1 indicates that the mean wind speeds in the White County area are above 8.2 km per hour in all 12 months.

The relative flatness of the area and favorable atmospheric conditions reduce pollution from coal facilities. This flatness prevents impact of plumes with high-level land. Additionally, the region has good meteorological conditions for the dispersion of pollutants. Good ventilation occurs throughout the region and stagnation conditions are rather infrequent.

Oxidation, photolysis, and other chemical reactions for each individual chemical pollutant, or among two or more pollutants, are possible in the plume. Sulfur- and nitrogen-containing compounds have been most extensively studied in this respect. Most atmospheric sulfate is formed by chemical conversion from the precursor, sulfur dioxide (SO_2). The amount of sulfate ($SO_4^=$) produced by direct combustion is small -- probably not more than a few percent of the total emitted sulfur.

In the power plant plumes that have been completely analyzed, the rate of conversion of sulfur dioxide to sulfate varied from 1/2 to 5 percent per hour. Condensation nuclei counts and aerosol size distribution profiles indicate that the major pathway is a homogeneous reaction, first order in sulfur dioxide, and probably involving the hydroxyl radical. The reaction rate depends on sunlight intensity and appears to also depend on water vapor concentration, background ozone levels, and the extent to which the plume has mixed with background air.

Nitric oxide (NO) is converted to nitrogen dioxide (NO_2) much more rapidly than sulfur dioxide is converted to sulfate. Typically, 50 percent of the nitric oxide has reacted by the time it has moved 30 km downwind from the plant. In studies involving power plant plumes, ambient ozone is almost totally consumed within the plume boundaries. Ozone is almost certainly responsible for the oxidation, since the amount of ozone removed was approximately equal to the amount of nitric oxide converted to nitrogen dioxide. However, in the reducing atmosphere of the coal liquefaction technology, ozone would not be expected. Even in coal combustion, the production of ozone is considered to be a phenomenon that exists only for a specific set of circumstances.

Other interactions of this type are possible between the many pollutants in the emissions. However, these possible interactions have not been studied as thoroughly as sulfur dioxide and the nitrogen oxides.

5.1.1.2 Soil and Geologic Factors

The most important surface soil properties affecting the potential distribution, and/or ecotoxicological effects of inorganic and organic contaminants, relate to the effectiveness of the organic and inorganic (clay) colloids in sorbing or trapping potentially toxic substances, soil pH, percolation rate, level of organic matter, and the activity of microorganisms.

The greater adsorptive capacities of the fine particles of clay and silt (i.e., particle diameters of one micron or less) compared to sand particles are widely recognized. Soil colloids are described as complex aluminosilicates coated with organic substances, broadly referred to as humic complexes; these organoaluminosilicate complexes exhibit selective ion adsorption. Many mineral colloid surfaces are covered with a coating of hydrous oxides of iron and manganese. These exist in amorphous or microcrystalline forms and in themselves exhibit a high specific surface area; up to 300 square meters per gram. The oxygen and hydroxyl groups of the hydrous oxides exert electrical charges which are pH dependent. Therefore, their capacity for sorption is pH dependent.

The dissolution and deposition of the coatings are also dependent upon the oxidation-reduction (redox) potential in the system. This parameter then becomes indirectly important in the adsorption or desorption of heavy metals. Sorption and desorption of metals further depend upon their concentrations in the percolate and upon the ones present. As with clays, there is an order of selectivity in adsorption. It is quite possible, however, that some heavy metals may move into the groundwater system prior to the exhaustion of exchange capacity.

In general, the amount of negative charge and surface area of clays is dependent on the clay type, being lowest for the kaolinite type and highest for the montmorillonite type. The primary surface soils (to a depth of about 1.8 m) occurring at the proposed White County site (e.g., the Hosmer-Ava-Bluford soil association) exhibit a silt loam texture at the surface down to a depth of from 22 to 48 cm. The subsoil materials range in texture from a heavy silt loam to light silty clay loam at 25 to 125 cm (Hosmer and Ava series), to a silty clay loam to clay loam at 48 to 125 cm. Thus, the major soils at the proposed site exhibit an extensive subsoil zone of clay accumulation (some kaolinite) that provides good potential for adsorption and exchange of anions and cations that may enter the subsurface water system. The negatively charged points of the clay surface hold cations (which carry a positive charge) by electrostatic and van der Waals forces. Usually the attraction is proportional to the positive charge on the cation. The upper limit for fixation of cations is referred to as the cation exchange capacity (CEC), and that of anions is known as the anion exchange capacity (AEC) (8). When the cation saturation point is reached, the percolate composition will remain stable. Factors affecting CEC and AEC include soil solute concentration, pH, and percolation rate. Thus, no quantitative predictions of the sorption characteristics of the Hosmer-Ava-Bluford association can be made short of a site-specific analysis.

Recent work by Johnson and Cole (8) indicates that anion production (HCO_3^-) and leaching (N and P) can be used effectively as an index of total ionic leaching through soils. In general, the order of affinities of major anions is $PO_4^{3-} > SO_4^{2-} > Cl^- = NO_3^-$. Highly weathered iron- and aluminum-rich soils have higher adsorption capacities than the younger iron- and aluminum-poor soils. The soils and geologic materials of the Hosmer-Ava-Bluford association appear intermediate in this regard (10,11).

The activities of soil microorganisms must be recognized in predicting the movement and composition of leachates. For example, under anaerobic soil conditions, microbes may convert trace elements to the less mobile sulfides. On the other hand, these activities under aerobic soil conditions may facilitate leaching of trace elements with subsequent passage into lower layers. The downward movement of trace elements in the soil column is a function of cation exchange, Eh, pH, and organic colloids. Trace elements with vacant "d"-orbitals, such as Cu, Zn, Fe, Mn, and Mo tend to be bound to soil organic matter. On the other hand, acidic soils tend to have high trace element availabilities (e.g., Mn and Ni) to the roots of crop plants. For selenium, the availability to plant roots in neutral to alkaline soils is reported to be greater than that in acidic soils, directly opposite to Mn and Ni.

Appendix Table A-V-11 shows some of the abiotic and biotic factors influencing the environmental transport of trace elements in soils. Key factors are the availability of trace elements for uptake and potential bioaccumulation by plants, ability of trace metals to travel through soil to groundwater, and the immobilization of trace metals in surface layers of soil from which it can be transported to nearby ecosystems by surface runoff, erosion, or windblown dust. Most nonpoint pollution sources can be attributed to the transport of contaminated sediments. Most cationic trace metals are immobilized in soil and are present in concentrations which would not pose a threat of groundwater contamination unless they are methylated (e.g., Hg), but anionic groups may pose a potential hazard. A theoretical study of the potential impact of a coal gasification plant on the trace element levels in soils surrounding the plant after 40 years of operation identified copper, mercury, molybdenum, and tin as elements whose endogenous soil levels would be greatly exceeded (12).

The representative nature of the Illinoian unconsolidated drift materials underlying the Hosmer-Ava-Bluford association of White County is illustrated by the data in Table 5-2.

TABLE 5-2. REPRESENTATIVE NATURE OF THE ILLINOIAN DRIFT (9)

Pleistocene series	Thickness (meters)	Depth to base (meters)
Illinoian Stage Glasford Formation		
Till, noncalcareous, very silty, light brown	4.6	4.6
Gravel, fine-to-medium-grained; till, calcareous, orange-colored	1.5	6.1
Till, calcareous, brownish-gray	3.0	9.1
Bedrock, shale (occurs as part of the bedrock).		

The nature of these unconsolidated materials can affect construction, mining, and land use activities. Beyond this, they are important sources of construction products and of groundwater (9). No site-specific logs of wells were uncovered. The thinnest layers of glacial drift (less than 7.6 m) are reported in southern Illinois. Bedrock is widely exposed in southern and western Illinois. Bedrock outcrops and areas where the bedrock is thinly covered by glacial drift, present opportunities for most pollutants to gain entry into groundwater deposits and travel sizeable distances through joints and channels. Of equal importance, the burial of hazardous wastes in these areas would introduce the danger of groundwater pollution (9). So far as is known, most of the bedrock outcrops occur south of the White County area.

5.1.1.3 Hydrologic Factors

5.1.1.3.1 Surface Waters

When effluents are discharged to surface waters, various factors contribute to the dispersion and dissipation of pollutants. The parameters which affect the dissipation of contaminants in water, shown in Table 5-3, will be discussed in the following chapter.

5.1.1.3.2 Dispersion and Dilution of Pollutants

The initial dispersion of contaminants results from the mixing and dilution of the waste discharge by the receiving stream. The primary receiving stream in this study would be the Wabash River, with the Little Wabash River potentially being the recipient of fugitive pollutants or accidental spills.

Contaminants in the effluent stream are diluted by the larger volume of water in the receiving stream. These contaminants are carried along with the flowing waters at a

TABLE 5-3. ABIOTIC FEATURES OF A HYDROLOGIC SYSTEM WHICH AFFECT DISSIPATIVE RATE OF CONTAMINANTS

Increases in environmental variable	Impact	Dissipative process
Sunlight hours	increases	photooxidation
Temperature	increases	chemical/biological oxidation processes
	decreases	dissolved oxygen
Wind velocity	increases	evaporation of volatiles
pH	may increase or decrease	solubility of metals and other compounds
Fineness of sediment	increases	adsorptive capacity
	decreases	seepage to and from groundwater aquifers
Precipitation	increases	most dissipative processes through increased flow volume, velocity, turbulence, turbidity, and sediment load
Flow volume	increases	dilution of contaminants
Turbulence	increases	-mixing of contaminants/sediments -speed of chemical reactions -evaporation of volatiles -dissolved oxygen -dissolved minerals
Turbidity	decreases	photooxidation

rate determined by the characteristics of the stream. Estimates of the time required for a contaminant to travel a given distance in a stream is of value in assessing the dispersion of contaminants routinely discharged into it. Such time-of-travel information would also be of vital importance in following the route of any hazardous material accidentally discharged into a natural waterway.

For the purpose of examining the dispersion or mixing effect of the receiving stream, the contaminants will be considered stable and undiminished by other dissipative forces. If a contaminant is stable or conservative, there will be a constant total amount of the material remaining in the stream as it is carried downstream. If the material is nonconservative, the amount of the material will become smaller as it goes downstream as a result of deterioration or of chemical reaction with either the air, water, or streambed.

When a material such as a dye or other contaminant is introduced into a stream it is immediately subject to the turbulence caused by the various velocities present. As a consequence the contaminant is mixed or dispersed. It is well known that there is considerable variation in the flow velocity throughout a cross section of a stream, as is illustrated by the typical stream cross section in Figure 5-1. Here it can be seen that, for a small element of the streamflow at the top of the stream near the center, the velocity will be considerably higher than it is near the streambed. This difference means that the dye or contaminant will be carried downstream by the fastest-moving element of the stream and, at the same time, will begin to be dispersed through the cross section. After a period of time, the dye will be carried by all elements of the stream water.

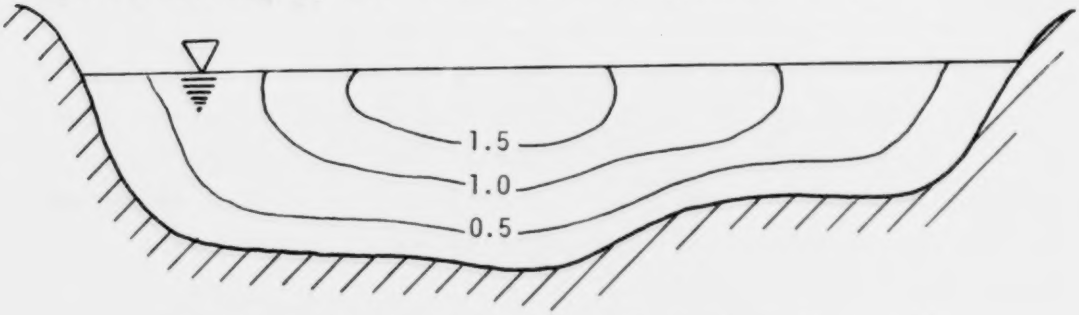

Figure 5-1. Typical lines of equal velocity in a stream cross section (13)

The principle of dispersion is illustrated in a practical example in Figure 5-2, which shows actual dye concentration curves, as measured by the State Water Survey in a time-of-travel study on the Vermilion River in Illinois, for a distance 24 km downstream. The three downstream curves have successively lower peaks and longer durations. The data illustrate what can be expected to occur by the natural process of dispersion in any stream. In this case, the dye tracer was considered to be stable; the total amount of the dye did not dissipate to any important extent during the study.

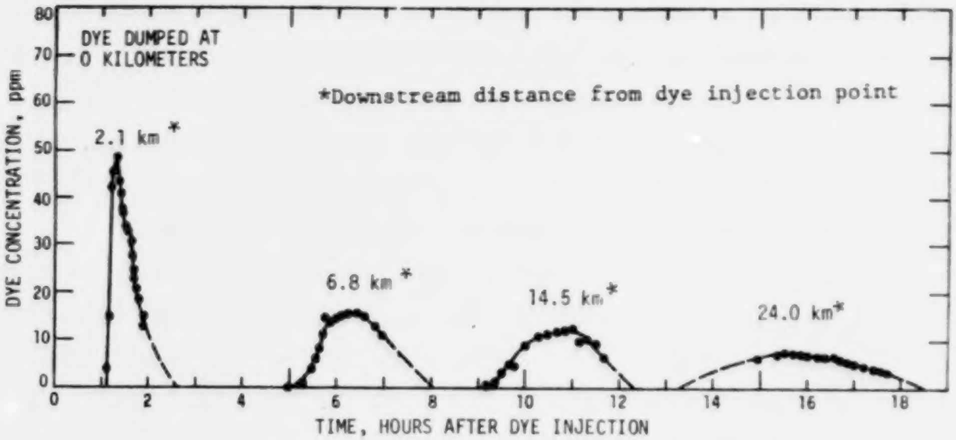

Figure 5-2. Concentration curves of a dye tracer introduced into the Vermilion River (13)

As a slug of dye material or contaminant is moved downstream, the velocity of the leading edge of the dye is faster than that of the peak concentration, with a decrease in the peak concentration as time passes. Stated as a generalized relationship,

$$V_l = 1.25V_p$$

where V_l is the velocity of the leading edge of the dye and V_p is the velocity of the peak concentration of the dye (13).

Time-of-travel rates have been estimated between various sections of the Wabash River. As shown in Table 5-4, the distance a contaminant could be expected to travel in one day ranges from 55 to 85 kilometers. Contaminants discharged at New Harmony would, in general, be expected to reach the junction of the Ohio River (83 km) within approximately one day.

TABLE 5-4. TIME-OF-TRAVEL RATES BETWEEN VARIOUS LOCATIONS ALONG THE WABASH RIVER (14)

Reach along Wabash	Distance (km)	Approximate average Time-of-travel (days)
Terre Haute - Riverton	84.3	1
Riverton - Vincennes	51.8	2
Vincennes - Mt. Carmel	56.8	1
Mt. Carmel - New Harmony	68.4	1
New Harmony - Ohio River	82.9	1

More precise time-of-travel rates have been determined for the Little Wabash River, with allowance made for variation in flow rates. As shown in the Little Wabash River time-of-travel graph (Figure 5-3), contaminants discharged into the river at Carmi would require one-half to one day (depending on the flow rate) to travel the 45 kilometers to the mouth at New Haven. The three curves on the graph show generalized flow conditions for high, medium, and low flows, representing frequencies of 10, 50, and 90 percent of the days per year. High flow is approximately bank full.

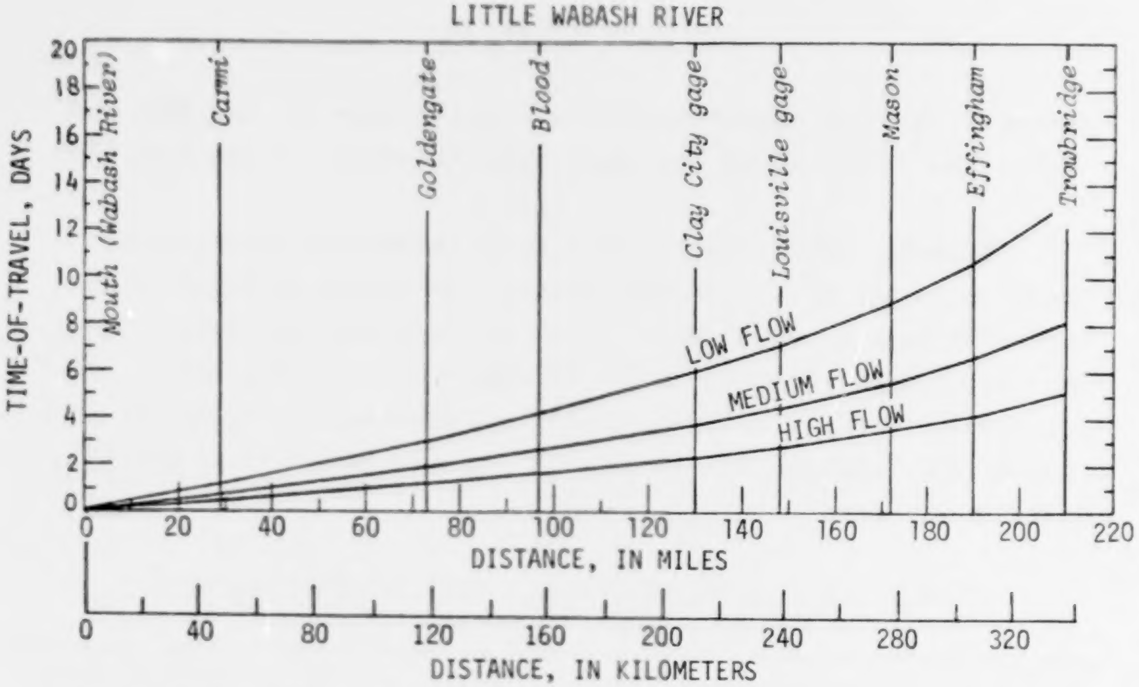

Figure 5-3. Time-of-travel graph, Little Wabash River (13)

Actual discharges of the Little Wabash River, shown in Table 5-5, can be utilized to determine the general category of particular flow rate.

TABLE 5-5. LITTLE WABASH RIVER: LOW, MEDIUM, AND HIGH FLOW RATES AT GAGING STATIONS (13)

		Flow (m^3/sec)		
USGS number	Station	Low F=0.90	Medium F=0.50	High F=0.10
3-3789	Louisville	0.11	2.34	47.01
3-3795	Below Clay City	0.13	3.40	73.62
3-3815	Carmi	0.79	14.50	229.37

5.1.1.3.3 Other Dissipative Forces

In addition to the physical mixing and movement of contaminants in surface water, numerous dissipative factors operate to reduce the contaminant levels. Compounds entering the natural water systems will undergo removal, decomposition, storage, or transport to the ocean. The significance of various dissipative processes is a function of the specific contaminant or contaminant category, as will be discussed later in this report.

Climatic conditions and the hydrologic features of the receiving stream (Wabash River and possibly the Little Wabash River) are all variables which may affect the rate at which contaminants are dissipated. A summary of abiotic features which may influence dissipation rate of pollutants in water has been presented in Table 5-3. Lack of understanding of the complex interaction of these environmental variables severely limits the reliability of the dissipation rate estimates for substances in a natural stream.

A study considering only the dissipative mechanism of evaporation, determined half-life values for several low solubility compounds. Table 5-6 shows the time required for half of the compound, considered at a depth of one meter below the water surface, to evaporate from the water. Assumptions made in this study represent ideal conditions; the actual rate of evaporation under environmental conditions may be substantially slower. Even when the limitations of this study are considered, the half-lives of the evaluated compounds are, nonetheless, surprisingly small. One consequence of these short half-life compounds is the difficulty introduced in monitoring effluents. If the effluent monitoring station is located far from the source, then by the time the water reaches the station much of the

TABLE 5-6. EVAPORATION PARAMETERS AND RATES FOR VARIOUS COMPOUNDS AT 25°C (15)

Compounds	Solubility, mg/l	Vapor pressure mm Hg	Half-life of compound at depth of 1 meter
Alkanes			
n-Octane	0.66	14.1	3.8 sec
2,2,4-Trimethylpentane	2.44	49.3	4.1 sec
Aromatics			
Benzene	1,780.	95.2	37.3 min
Toluene	515.	28.4	30.6 min
o-Xylene	175.	6.6	38.8 min
Cumene	50.	4.6	14.2 min
Naphthalene	33.	0.23	2.9 hr
Biphenyl	7.48	0.057	2.2 hr

contaminant may have already moved from the water to the atmosphere. If the contaminant is potentially hazardous and is not readily degraded in the atmosphere, then the quantity of contaminants discharged to the atmosphere may be underestimated.

Chemical reactions in the water systems can result in the breakdown of pollutants into simpler, non-hazardous components. Some chemical interactions may, however, result in the production of substances more toxic than the original contaminant.

Most chemical reactions occur at the air-water interface, the sediment-water interface, or the boundaries between the water and the particles that are suspended in the water. Materials that concentrate at the air-water interface are subject to oxidation, ultraviolet radiation, evaporation of volatile constituents, and polymerization (16). Environmental factors such as increased flow velocity and turbulence enhance the probability of contaminants being distributed to these various interfaces, thereby increasing the speed of chemical degradation.

5.1.1.3.4 Groundwater

Potential groundwater contamination is a major environmental hazard which has in the past received only limited consideration. An important aspect of groundwater contamination is the fact that it may persist for years, decades, or even centuries. This is in marked contrast to surface water pollution. Many of the degradation factors which actively operate to dissipate a contaminant in surface waters are absent or operate at much slower rates in groundwater aquifers. It is important, therefore, to control groundwater pollution by regulating the source of contamination. The lack of specific data, including that of the soils and hydrological conditions at the site, precludes the possibility of calculating the rate of contaminant movements into and through the groundwater system. The focus of this section will, therefore, be a generic description of groundwater contamination, with incorporation of site-specific data where available.

In order to appreciate the magnitude and severity of groundwater contamination, the hydrologic system itself, the mechanism of groundwater contamination, and the environmental hazards must be understood. A discussion of aquifer recharge/discharge and the hydrogeologic conditions affecting groundwater contamination is given in Appendix V. A general understanding of the way in which groundwater is recharged and discharged, along with the factors affecting the rate and direction of movement, is vital to assessing the potential impact of an SRC facility on the existing water resources at a specific site.

5.1.1.3.5 Contamination of Groundwater

With regard to coal liquefaction, two major potential sources of groundwater pollution are surface impoundments of various liquids and solid waste landfills. Impoundments in the form of tailing ponds or sludge dewatering lagoons are surface depressions in which waste fluids are pumped or drained to the pond via pipeline or drainage ditch. The suspended solids then settle to the floor of the pond and the remaining portion (effluent) is either reused, discharged into local surface water, or spread on land. As the solids settle, the pond fills with sediment and is either abandoned or dredged to create new storage space.

Seepage is the most prevalent source of groundwater contamination from ponded wastes. Levels of potential pollutants from such wastes are given in Chapter 3. Other routes by which impoundments may contribute to pollution problems are through pond overflow and dike leakage, both of which can recharge a local aquifer with contaminated water. Also, prior to abandonment of the waste site, failure to properly cover the area (thus preventing or limiting the rainfall infiltration) could result in the area continuing to be a contamination source.

Solid waste land disposal sites can also be sources of groundwater contamination, because of the generation of leachate caused by water percolating through the refuse. Precipitation falling on a site either becomes runoff, returns to the atmosphere via evaporation and transpiration (water use by plants), or infiltrates the refuse. This infiltrating water ultimately will form leachate containing soluble and suspended contaminants.

The process of leachate formation and subsequent groundwater contamination is dependent upon the amount of water which passes through the refuse. Water which infiltrates the surface of the cover will first be subject to evaporation and plant transpiration. Any water in excess of field capacity will percolate through the layers of solid waste. Additional surface runoff from the surrounding land, moisture contained in the solid or liquid waste placed in the fill, moisture from solid-waste decomposition, and water entering through the bottom or sides of the site also contribute to the generation of leachate.

Figure 5-4 illustrates the flow of contaminants from a surface source such as a disposal pit, lagoon, or basin. Note that the contaminated water flows downward to form a recharge mound at the water table and then moves laterally outward below the water table.

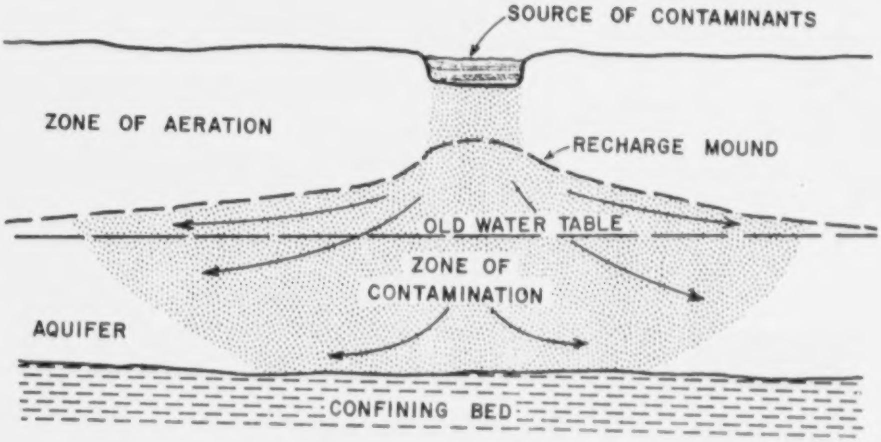

Figure 5-4. Percolation of contaminants from a disposal pit to a water table aquifer (17)

Figure 5-5 indicates contaminant movement from a surface stream or lake to a nearby pumping well. The drawdown of the water table induces recharge of surface water to groundwater. Thus, continuous pumping from municipal water supply wells located adjacent to a polluted stream may lead to the contamination of the water supply.

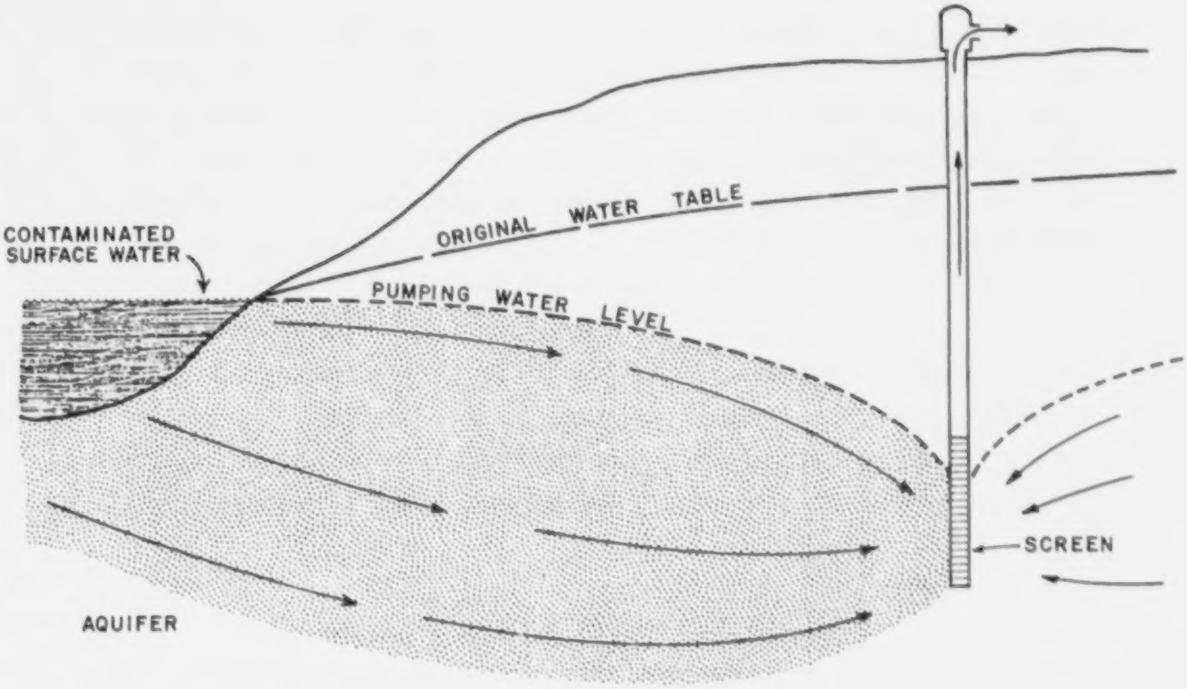

Figure 5-5. How contaminated water can be induced to flow from a surface stream to a well (17)

5.1.1.3.6 Mechanism of Contamination (17)

Contaminants in groundwater tend to be removed or lowered in concentration with time and with distance traveled. Mechanisms involved include adsorption, dispersion and dilution, and decay. The rate of attenuation is a function of the type of contaminant and of the local hydrogeologic framework. Attenuation in an aquifer is extremely slow, as is the movement of groundwater (typically less than 0.6 m/day). Therefore, contaminants within the groundwater system do not mix readily with native water and move as:

(1) individual bodies or slugs (e.g., caused by intermittent filling of and seepage from wastewater impoundments); (2) local plumes (e.g., caused by continual flow of leachate from beneath a landfill toward a pumping well); and (3) masses of degraded water (e.g., caused by a large number of septic tanks discharging nitrate-enriched water which travels with the regional groundwater flow pattern).

Specific statements cannot be made about the distances that contaminants will travel because of the wide variability of aquifer conditions and types of contaminants. Also, each constituent from a source of contamination may have a different attenuation rate, and the distance over which contamination is present will vary with each component. Yet, certain generalizations can be made. For fine-grained alluvial aquifers, contaminants such as bacteria, viruses, organic materials, pesticides, and most radioactive materials, are usually removed by adsorption within distances of less than 100 m. However, most common ions in solution move unimpeded through these aquifers, subject only to the slow processes of attenuation.

A hypothetical example of a waste disposal site is shown in Figure 5-6. Here groundwater flows toward a river. Zones A, B, C, D, and E represent essentially stable limits for different contaminants resulting from the steady release of liquid wastes of unchanging composition. Contaminants form a plume of contaminated water extending downgradient from the contamination source until they attenuate to acceptable quality levels.

The shape and size of a plume depend upon the local geology, the groundwater flow, the type and concentration of contaminants, the continuity of waste disposal, and any modifications of the groundwater system by man, such as well

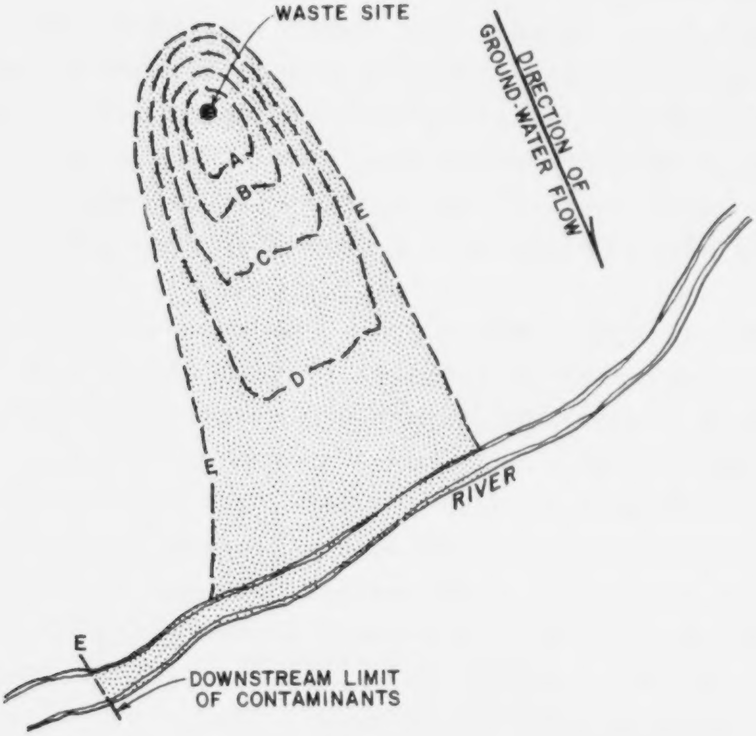
WASTE SITE
DIRECTION OF GROUND-WATER FLOW
A
B
C
D
E
E
E
RIVER
DOWNSTREAM LIMIT OF CONTAMINANTS

Figure 5-6. Hypothetical dispersal of contaminants in mixed wastes through a water table aquifer (17)

pumping. Where groundwater is moving relatively rapidly, a plume from a point source will tend to be long and thin; but where the flow rate is low, the contaminant will tend to spread more laterally to form a somewhat wider plume. Irregular plumes can be created by local influences such as pumping wells and variations in permeability.

In marked contrast to surface-water pollution, groundwater contamination may persist for many years. The average residence time of groundwater is on the order of 200 years; consequently, a contaminant which is not readily decayed or sorbed underground can remain as a degrading influence on the resource for indefinite periods. Comparable residence time for water in a stream or river is on the order of 10 days. Controlling groundwater contamination, therefore, is more difficult than controlling surface water contamination. Underground contamination control is best achieved by regulating the source of contamination. A secondary control is physical entrapment and, when feasible, removing the contaminated water from the underground.

5.1.2 Characteristics of Chemical Pollutants

5.1.2.1 Physical/Chemical Interactions

The behavior of a chemical pollutant introduced into the environment depends largely upon two factors -- the nature of its surroundings and the physical-chemical properties of the pollutant. For example, transformations can occur in all environmental media -- the hydrosphere, lithosphere, atmosphere, and biotic components of the environment. Likewise, in the medium, the behavior of a chemical is determined by its solubility, vapor pressure, adsorption ability, and degradability.

5.1.2.1.1 Inorganics

The fate of compounds in natural water systems is influenced by their solubilities: the solubility determining whether it will go into solution, become suspended in the water column, or adsorbed onto the sediments.

The solubility product constants for the elements, inorganic compounds, and complexes associated with an SRC technology are presented and discussed in Appendix Tables A-V-7, A-V-8, and A-V-9. In general, information of this type can be used to predict if an element in an effluent stream will be in a soluble form or in an insoluble form. The presence of an element in a soluble form implies that the element will travel at the same rate as that of the receiving water, and thus will be more subjected to exposure, absorption, and assimilation by aquatic biota. Elements in insoluble forms are more likely to be adsorbed onto sediments. However, "soluble" is a relative term and significant concentrations of solvated ions can occur for the more toxic elements, even if they occur as insoluble forms.

Unfortunately, the solubility characteristics of the elements can be changed from the behavior predicted in the above-mentioned tables by environmental interactions. For example, elemental mercury is considered to be quite "insoluble"; however, microbial methylation in sediments can change the form of mercury to a compound which is quite soluble and easily absorbed by aquatic biota. This mercury is then in a form which can be easily absorbed by predators of the aquatic biota, including fish-eating birds and humans.

Volatility of elements and inorganic compounds is usually not considered significant since the boiling points at atmospheric pressure are very high for most of these materials, except for the hydrides (18). A high boiling point implies a low vapor pressure. The quantity of a compound expected to volatilize from water can be predicted from its vapor pressure; this information is discussed elsewhere in this report. Hydrides are usually unstable in aqueous solution. Exceptions to this rule include the hydrides of copper and germanium. These compounds, if present, may volatilize from aqueous mixtures. Methylation of an element, such as the microbial methylation of mercury, can also lead to transfer of the element from the water phase to the air phase, since the methylated form is much more volatile.

The melting points, boiling points, and solubilities of selected inorganic compounds are presented in Appendix Table A-V-10. In order to be included in this table, a particular inorganic compound had to have a boiling point less than 100°C and not decompose when contacting water. Thus, these compounds will tend to be stable in the environment and may tend to remain in the atmosphere. The particular air/water partitioning for each individual compound will depend on the water solubility as well as the boiling point. A more extensive listing of these properties was published in *Industrial and Engineering Chemistry* (19).

5.1.2.1.2 Organics

Knowledge of the organic pollutants potentially emanating from an SRC facility is extremely limited. Waste streams containing organic constituents could contain hundreds of different compounds, the concentrations of which would depend upon the operating parameters as well as the type of feed coal. Rather than trying to characterize specific individual compounds, an attempt will be made to examine certain groups of compounds which are presumed to be present in the largest quantities and/or to be the most toxic or hazardous. The compound groups to be characterized include phenols (MEG category No. 18), fused aromatic hydrocarbons and their derivatives (commonly called polynuclear aromatic hydrocarbons or PAH, MEG Category No. 21), aliphatic hydrocarbons -- alkanes and cyclic alkanes (MEG Category No. 1A), aliphatic hydrocarbons -- alkenes, cyclic alkenes, and dienes (MEG Category 1B), and benzene and substituted benzene hydrocarbons (MEG Category 15).

5.1.2.1.3 Phenol

Phenol is very soluble in water and has a moderately low vapor pressure (1 mm Hg at 40.1°C). It will remain in solution in natural waters under most conditions with low losses by volatilization. Soil particles may serve as sorption sites to remove phenol from solution. However, as a weak acid, phenol solubility will increase slightly in alkaline water and will result in leaching occurring more readily from alkaline soils. Phenol does not decompose photolytically under visible light, but is decomposed primarily by microbial action (20).

5.1.2.1.4 Fused Aromatic Hydrocarbons

The high molecular weight and lack of polar substituent groups attached to the aromatic rings make fused aromatic hydrocarbons [polynuclear aromatic hydrocarbons (PAH)] very insoluble in water. As is true with other organics, the toxicity of PAH compounds for aquatic organisms seems to be universally related to the water solubility -- the less the water solubility, the more toxic the compound. Table 5-7 reviews the reported solubilities for polynuclear aromatic hydrocarbons given in the scientific literature. Solubility of PAH in natural water systems seems to be poorly defined. Some of the inconsistencies in measured values may be the result of using different experimental techniques and conditions. Although PAH have a low solubility in water, they may occur in liquefaction waste streams as aqueous solutions associated with or adsorbed onto a variety of particulate and colloidal materials and thereby be transported through the water environment (24).

The volatility of PAH compounds at 25°C is very low, ranging from 6.8×10^{-4} torr for phenanthrene (three rings)

TABLE 5-7. SOLUBILITY OF FUSED AROMATIC HYDROCARBONS IN WATER (21,22,23)

Compound	Experimental conditions	Solubility (ppm)
Phenanthrene	Shaking crystals in distilled water for 3 months at 25°C	1,600
1,2-Dibenzanthracene		10
Pyrene		175
Anthracene		75
Chrysene		6
Naphthacene		1.5
1,2-5,6-Dibenzanthracene		0.6
2-Methylnaphthalene		24,600
Naphthalene	Standard hydrocarbons dissolved in hexane added to doubly distilled water or artificial sea water and shaken for 12 hours at 25°C	31,300; 22,000 (dw) (sw)
Biphenyl		7,450; 4,760 (dw) (sw)
Acenaphthene		3,470
Phenanthrene		1,070; 710 (dw) (sw)
Mixtures of naphthalene and phenanthrene (solubility of phenanthrene)		1,060
Mixtures of biphenyl and phenanthrene		910
Mixtures of acenaphthene and phenanthrene		1,010
Mixtures of 2-Methylnaphthalene and phenanthrene		800
Mixtures of naphthalene and acenaphthene and phenanthrene (solubility of phenanthrene)		1,010

(continued)

TABLE 5-7. (continued)

Compound	Experimental conditions	Solubility (ppm)
Phenanthrene	Nephelometric method at 27°C (crystals of hydrocarbons added)	1,600
4,5-Methylphenanthrene		1,100
Fluoranthene		240
Pyrene		165
Anthracene		75
9-Methyl-1,2-benzanthracene		66
1'-Methyl-1,2-benzanthracene		55
10-Methyl-1,2-benzanthracene		55
1,2-benzanthracene		11
6-Methylchrysene		65
5-Methylchrysene		62
Chrysene		1.5
5,6-Dimethylchrysene		25
5-Methyl-3,4-benzopyrene		0.8
3,4-Benzopyrene		4
20-Methylcholanthrene		1.5
Cholanthrene		3.5
Picene		2.5
Perylene		0.5
Naphthacene		1.0
1,2,7,8-Dibenzanthracene		12
1,2,5,6-Dibenzanthracene		<0.5
9,10-Dimethyl-1,2-benzanthracene		43
10-Amyl-1,2-benzanthracene		0.8
10-Ethyl-1,2-benzanthracene		45

to 1.5 x 10^{-12} torr for coronene (seven rings). The adsorption of PAH compounds to particles in either air or water reduces their activity and therefore makes it unlikely that significant quantities of these compounds will pass from the water to the air by co-distillation (25). PAH are readily adsorbed to particulate matter, which can be deposited on land or water surfaces. The PAH, while adsorbed on particulates or in solution, may eventually reach the beds of the various water bodies and in the absence of light and under anaerobic conditions, remain in a stable condition for long periods (26).

In the air, PAH compounds are highly reactive. There is evidence that they are degraded in the atmosphere by photooxidation, by reaction with atmospheric oxidants, and by reaction with sulfur dioxides (27).

Because PAH are carried by suspended particulate matter, their longevity in air depends on the lifetime of the carrier aerosol in air and on chemical alteration of the PAH themselves. Initial estimates of atmospheric residence times of particles less than 5 m in diameter exceed 100 hours under dry atmospheric conditions. Chemical reactivity in the presence of sunlight may lead to transition of PAH to other material in several hours. Without sunlight, its lifetime may be much longer (27).

5.1.2.1.5 Alkanes, Alkenes, and Aromatic Hydrocarbons

The solubilities of selected hydrocarbons are given in Tables 5-8 and 5-9. Studies indicate that chain-branching increases the water solubility of paraffin, olefin, and acetylene hydrocarbons, but not of cycloparaffin, cycloolefin, and aromatic hydrocarbons. For each homologous

TABLE 5-8. SOLUBILITY IN WATER AT ROOM TEMPERATURE OF PARAFFIN, BRANCHED-CHAIN PARAFFIN, AND OLEFIN HYDROCARBONS (28)

Hydrocarbon	Solubility at 25°C (g of hydrocarbon/10^6 g of water)		Molar vol (ml/mole at 20°C)
	Reference 28[a]	Other literature[b]	
Alkanes			
Methane	24.4 ± 1.0	21.7, 22.8, 21.5	39
Ethane	60.4 ± 1.3	56.6, 58.3, 51.6	55
Propane	62.4 ± 2.1	67.0, 65.6	88.1
n-Butane	61.4 ± 2.6	72.7, 67.2	100.4
Isobutane	48.9 ± 2.1		104.3
n-Pentane	38.5 ± 2.0	360	115.2
Isopentane	47.8 ± 1.6		116.4
2,2-Dimethylpropane	33.2 ± 1.0		122.1
n-Hexane	9.5 ± 1.3	140, 36	130.7
2-Methylpentane	13.8 ± 0.9		131.9
3-Methylpentane	12.8 ± 0.6		129.7
2,2-Dimethylbutane	18.4 ± 1.3		132.7
n-Heptane	2.93 ± 0.20	50, 10	146.5
2,4-Dimethylpentane	4.06 ± 0.29		148.9
n-Octane	0.66 ± 0.06	14	162.6
2,2,4-Trimethylpentane	2.44 ± 0.12		165.1
2,2,5-Trimethylhexane	1.15 ± 0.08		181.3
Alkenes			
Ethene	131 ± 10	134, 131	54.5
Propene	200 ± 27	183 at 30°C	81.9
1-Butene	222 ± 10		94.3
2-Methylpropene	263 ± 23	289, 314	94.4
1-Pentene	148 ± 7		109.5
2-Pentene	203 ± 8		107.0-108.2[c]
3-Methyl-1-butene	130 ± 14		111.8
1-Hexane	50 ± 1.2		125.0
2-Methyl-1-pentene	78 ± 3.2		123.4
4-Methyl-1-pentene	48 ± 2.6		126.7
2-Heptene	15 ± 1.4		138.7-140.0[c]
1-Octene	2.7 ± 0.2		157.0
Diakenes			
1,3-Butadiene	735 ± 20		87.1
2-Methyl-1,3-butadiene	642 ± 10		100.0
1,4-Pentadiene	558 ± 27		103.1
1,5-Hexadiene	169 ± 6		118.7
1,6-Heptadiene	44 ± 3		134.0

[a] Numbers following ± symbol indicate standard deviation from mean.

[b] See reference (28) for sources of the values given.

[c] Molar volume for cis-trans forms.

TABLE 5-9. ROUTES OF ABSORPTION AND EXCRETION FOR VARIOUS ELEMENTS (18)

Element	Excreted in sweat	Excreted in feces	Excreted in urine	Excreted in breath	Absorbed in lung	Intestinal absorption	Cross gills	Cross Placental barrier	Cross skin
Antimony		+	≥10%		+	5-70% (little as Sb^{+3} or Sb^{+5})			
Arsenic		+	10-80%	±	+	5-70%			+
Beryllium		largely			+	poor (<5%)			
Boron			+		+	70%			
Bromine			+		+	70%			
Cadmium		85% of intake	10% of intake		+	poor (<5%)		+	
Chlorine			+		+	>70%			
Chromium		+	+			>70%			
Cobalt			≥10%			5-70%			
Copper			≥10%		+	5-70%			
Fluorine	±		+		25-100%	>70%		+	
Iodine			+		+	70%			
Lead		largely	+		primarily (25-50%)	poor (5-10%)	+	+	-
Manganese			2-3%		major	4%			

(continued)

TABLE 5-9. (continued)

Element	Excreted in sweat	Excreted in feces	Excreted in urine	Excreted in breath	Absorbed in lung	Intestinal absorption	Cross gills	Cross Placental barrier	Cross skin
Mercury	+	predominant (85%)	≥10%	+	50-100%	inorganic: 2-25% organic: 50-100%		+	+
Nickel	+		≥10%		+	5-70%			+
Nitrates/ nitrites						+		+	
Phosphorus			≥10%		+	5-70%			
Ruthenium		largely			+	<5%			
Selenium	+	+	50-80%	+	+	35-85%			+
Sulfur			≥10%		+	5-70%			
Tellurium			+		+	>70%			
Thallium		+	+					limited	+
Tin		largely			+	5-70%			
Vanadium		+	+			>70%			
Zinc		largely	+		+	<5%	+		+

series of hydrocarbons, the logarithm of the solubility in water was found to be a linear fraction of the hydrocarbon molar volume.

The presence in water of certain natural or dissolved organic substances has been shown to increase the solubility of some hydrocarbons. Removal of this dissolved organic matter from natural samples resulted in a 50 to 99 percent decrease in the amounts of hydrocarbons (primarily n-alkanes) solubilized. Solubilities of phenanthrene and anthracene were unaffected by the removal. However, high concentrations of surfactants (10 to 50 mg/liter) have been shown to increase the water solubility of benzo-a-pyrene (BaP) by a factor of 2 to 10 (29).

5.1.2.2 Biological Interactions

In addition to understanding the physical-chemical removal processes, an understanding of the biological cycling of various contaminants is essential in order to evaluate the potential impact of a substance. The effect of a contaminant on an ecosystem is to a large extent a reflection of the degree to which it is taken up, metabolized, accumulated, and/or excreted by specific organisms.

The following section will discuss the biological cycling of contaminants in organisms (including uptake, metabolism, elimination, and retention in organisms) as well as the ecotoxicological effects (acute toxicity, carcinogenicity, mutagenicity, teratogenicity and chronic toxicity).

5.1.2.2.1 Inorganics

In order to be a toxicant, a material must interact with a vital function in a living system. Thus, the toxicant effect is a function of the dose level, the time of contact, and the pH and salinity of the medium, as well as other parameters. The efficiency of absorption of a potential toxicant by an organism depends on the element and the form in which the element occurs in the medium, plus the physiological state, the age, and even the habits of the organism. A general description of the approximate rate of absorption and excretion is found in Table 5-9. These data are based on laboratory experiments with a number of mammals as well as human studies. Since the absorption of trace elements depends on many factors, the numbers in Table 5-9 are only indicative of general trends.

The absorption of an inorganic element depends upon the chemical form of the element. In general, univalent cations readily diffuse across the gut wall, become more or less uniformly distributed in the soft tissues, and are fairly rapidly eliminated in urine. Divalent cations appear to be much less readily absorbed across the gut wall. It is still uncertain how efficiently major elements such as calcium and magnesium are absorbed, since the reverse process may take place lower down in the gut. Once absorbed, most divalent cations concentrate in bone and are relatively slowly eliminated in the urine and feces. The affinity for bone is greatest for those ions most closely resembling calcium. Thus, barium and strontium are notable bone-seekers, but copper, cobalt, and nickel diffuse into the soft tissues and a sizeable percentage is excreted in the urine. Polyvalent cations diffuse still less readily across the gut wall, and remain in the fecal material. It should be noted, however, that the extent of absorption across the intestinal wall can be profoundly modified by other components of the diet. Well-known examples include the effect of Vitamin D on calcium absorption, of sulfate on barium and molybdenum absorption, and of aluminum on the absorption of phosphate (30).

The amount of inorganic pollutants taken up by aquatic bottom dwellers is a function of the type of sediment to which the pollutant is adsorbed. For example, a laboratory study of the uptake of sediment-bound heavy metals by the clam, Macoma balthica, showed the availability of these metals was dependent upon the physical and chemical nature of the metal-sediment association. Laboratory studies of bioaccumulation from individual sedimentary trace-element sinks labeled with radioactive tracers of silver, cobalt, and zinc indicated that bioavailability varied among metals within a given sink and among sinks for a given metal. Little bioaccumulation was observed from several sinks that may be common in nature, i.e., little zinc or cobalt uptake was observed when those metals were coprecipitated with amorphic iron oxide or manganese oxide. However, silver, cobalt, and zinc were all taken up from detrital organics, and silver was accumulated by the clam from the iron oxide precipitate. Even quantitatively minor sinks within aquatic sediments may be important sources of some metals. Uptake rates of cobalt and zinc from biogenic carbonates (e.g., crushed clam shells) were significantly greater than rates of uptake from other sinks. Likewise, silver uptake from both biogenic carbonates and synthetic calcites was greater than silver uptake from iron oxides or detrital organics. Sinks from which bioaccumulation of bound metals was greatest also showed the greatest rate of sediment-to-water desorption of metals. When such sinks are abundant in nature, bioavailability of sediment-bound metals may be enhanced, both through increased uptake from ingested particulates by deposit feeders and through increased sedimentary desorption, which results in higher concentrations of solute metals (31).

Uptake by both polychaetes (Nereis succinea) and deposit-feeding shrimp (Palaemon debilis) of mercury bound to highly organic estuarine sediment, is significantly less than uptake of mercury bound to iron oxide-dominated sediments characteristic of runoff in Hawaii. In contrast, accumulation of zinc by the polychaete, *Nereis diversicolor*, differs little when uptake of organic particulate-bound zinc on the surface of marine sediments is compared with uptake of iron oxide-bound zinc on the surface of such sediments. Experiments with mixed sediments may be influenced by both metal mobility among binding types and/or selective feeding of experimental organisms. Preliminary experiments showed that iron oxide-bound cadmium was much more available to *Macoma balthica* than was cadmium bound to organic particulates. Coating the iron oxide particles by stimulation of bacterial growth also significantly reduced cadmium uptake by the clam. Cadmium, lead, and zinc concentrations in earthworms apparently vary with soil series, which is in keeping with known variations in chemical extractability of trace elements between soil series (31, 32).

Precise predictions of lead concentrations in deposit-feeding clams may be obtained from the lead-iron ratio extracted from estuarine sediments by weak acids. Lead analyses were conducted on surface sediments and clams, *Scrobicularia plana*, collected from 40 stations in 18 estuaries of southwest England. Total lead concentrations ranged from 41 to 1600 μg/g in the sediments and 14 to 1016 μg/g in the clams. Variations in the lead content of the animals were not predictable from total lead concentrations in the sediment. Statistical evidence suggested amorphic iron oxides were an important sink for lead in the sediments. At stations where high concentrations of iron were extracted from the sediments, the availability of lead to the clams was inhibited. Among all stations lead concentrations in the clams were strongly correlated with the lead-iron ratio in the sediments (r = 0.97; p = much less than 0.001) (33).

Selective feeding of most benthic species can lead to differential metal distribution. For example, concentrations of zinc are generally higher in subsurface-feeding polychaetes than in polychaetes that feed at the sediment-water interface. Where significant amounts of zinc are sorbed to iron or manganese oxides, solubilization of zinc would be likely upon dissolution of the amorphic oxides in the anoxic interstitium. Upward diffusion of dissolved iron, manganese, and zinc within the sediment may result in oxidation and reprecipitation at the aerobic sediment-water interface. However, zinc occluded in amorphic oxides of iron and manganese appears to be one of the least available forms of zinc to deposit-feeding clams. Thus, while surface-feeding polychaetes are ingesting zinc in its least available form (and, quite possibly, protected from interstitial solute zinc by their burrow walls), subsurface feeders (which often do not use walled burrows) may be exposed to elevated levels of highly available zinc in interstitial waters. In such a way, diagenetic processes in estuarine sediments may influence zinc concentrations in estuarine polychaetes (32). The rate of uptake of metallic compounds also may be strongly influenced by temperature. Fowler and Benayoun (34) observed a 400-percent increase in the rate of cadmium uptake in shrimp over a 26-day period at 22°C, as opposed to 8°C. On the other hand, mussels were not affected by the change in temperature (34).

The diet of animals may influence the uptake of elements. Bioaccumulation (discussed subsequently) generally results in higher concentrations of pollutants in animals than in plants; this can lead to higher pollutant concentrations in carnivorous species. Figure 5-7 shows the

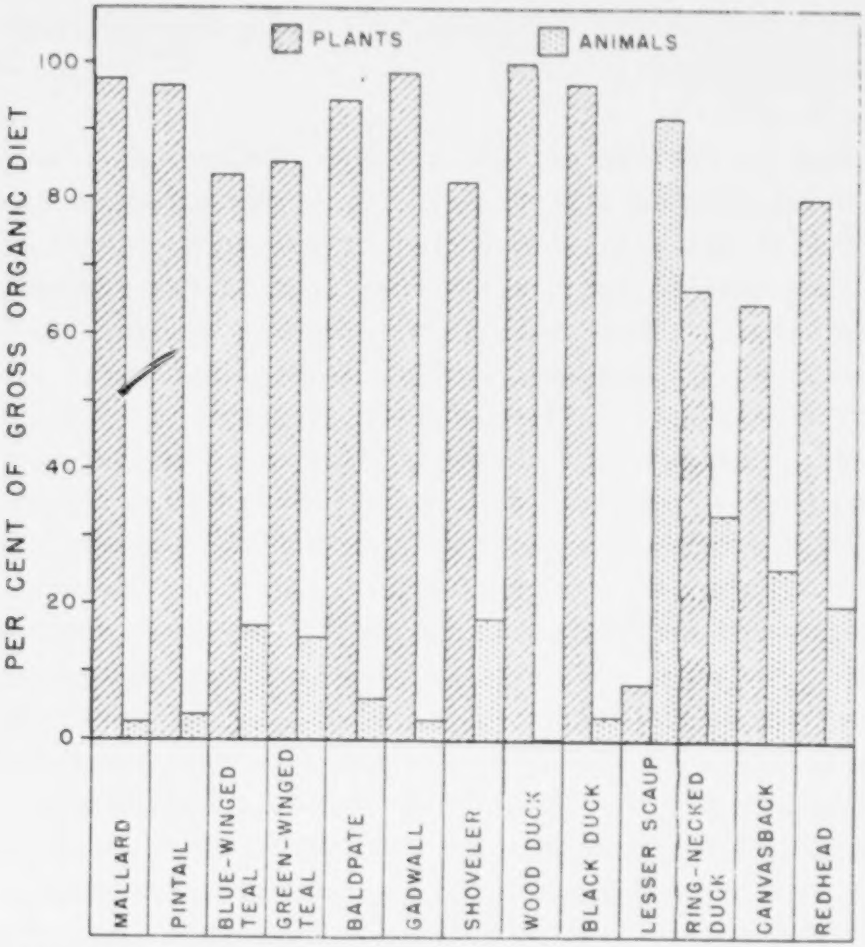

Figure 5-7. Diets of migratory waterfowl killed in Illinois (35)

different diets of migratory waterfowl killed in Illinois; this figure indicates that the lesser scaup would have a diet that exposes this species to more dietary pollutants than the mallard. Based on this information alone, we would expect the lesser scaup to be more sensitive to pollutants than the mallard (35).

The uptake of metals from soils by plants may depend on selectivity of the plant and on the availability of other minerals. Such uptake can also be modified by other factors, such as the amounts of water and fertilizer, or chemical composition of soil (36).

Animals for the most part obtain their minerals from plants. Direct ingestion of soil or deposition of soil on foliage may account for a considerable amount of some mineral intake by animals. On the basis of the nature of the element, it may be accumulated in certain organs of the animals or it may be metabolized from the body, so that a definite relationship of the body burden in an animal to its environmental exposure may not be attained. The tissue contents of an animal for various elements may depend on several factors, such as the type and nature of vegetation; the amount and duration of ingestion; the age, sex, and species of the animal; and the presence of other interacting elements. For example, the interactions of copper and molybdenum in eliciting animal toxicities are well known (36).

5.1.2.2.2 Inhalation and Absorption

The effect of the size of particulates in relation to their deposition in the respiratory tract is as follows:

TABLE 5-10. EFFECT OF THE SIZE OF PARTICULATES ON DEPOSITION IN THE RESPIRATORY TRACT (37)

Particle size (microns)	Lung deposition[a] (percent)	Tracheal-bronchial-nasal deposition[a] (percent)
0.1	50	9
0.5	30	16
2.0	20	43
5.0	10	68
10.0	5	83

[a] The percentage not deposited was exhaled.

The type of information relates to absorption, since pollutants in particles deposited in the lung are subjected to absorption by direct leaching from the particle by the lung fluids or by phagocytosis. Particles deposited in the trachea or nasal sinuses are more likely to find their way into the digestive tract, where the mechanisms of absorption are much different. Some studies indicate that the concentration of certain elements may be greater in the smaller particulates (of coal for example) than in the larger particulates, while for other elements the opposite effect may be observed (34).

5.1.2.2.3 Implications of Biological Interactions

These results have several practical implications, the most important being that metal speciation must be considered when assessing the biological impact of aqueous-metal systems. Present water quality criteria and tolerance limits are stated exclusively in terms of total metal content; yet trace metal availability and toxicity in the aquatic environment are dependent on other factors. Metals do not always exist as free hydrated ionic species in solution, but rather are associated with available electron-donating ligands to form complex molecules which themselves have an effect on metal availability to living organisms. For more useful and accurate measures of the environmental impact of metal pollutants, water quality criteria and tolerance limits should, therefore, be based upon toxicity tests. In this regard, consideration should be given to the chemistry of the aquatic environment in terms of such factors as pH, pE, ionic strength, type and concentration of the complexing agents present, and the specific and non-specific interactions responsible for metal solubility, transport, and distribution in natural water systems (39).

5.1.2.2.4 Metabolism of Inorganic Substances

Some compounds of antimony (40), arsenic (41,42), lead (43), mercury, molybdenum, nickel, selenium, silver, sulfur, titanium, vanadium, and zinc (30,43), or the elements themselves, are subject to microbial metabolism and undergo oxidation, reduction, methylation, and/or demethylation. The methylated forms are highly toxic, cross membrane barriers with relative ease, and are more likely to become airborne because they are more volatile than the elements themselves (34). Microbial action also can affect the availability of many elements in soils and waters. Silicate minerals are attacked by the organic acid liberated by *Bacillus siliceus* (30). Organic matter fermented by bacteria in the absence of oxygen can dissolve considerable amounts of cobaltous oxide, cupric oxide, ferric oxide, manganese dioxide, molybdenum trioxide, lead dioxide, and zinc and smaller amounts of chromium trioxide, nickel monoxide, titanium dioxide, and vanadium pentoxide (30).

The kind and rate of microbial metabolism depend, in part, on the chemical form of the trace element. For example, alkylation of inorganic lead salts is considered a very difficult reaction mechanism in view of the instability of the postulated first intermediate, monomethyl lead salt. However, the conversion of lead nitrate and lead chloride to tetramethyl lead was reported for a mixed bacterial culture from Lake Ontario (44). No such transformation was detected with lead hydroxide, lead cyanide, lead oxide, lead bromide, or lead palmate. The methylation of trimethyl lead acetate to volatile tetramethyl lead is, in contrast, a fairly simple transformation for bacteria to make (45).

In the laboratory, bacterial methylation activity is frequently higher under anaerobic conditions than under aerobic conditions. However, in natural fresh water the reverse seems to be true. In sediments, where anaerobic conditions are more likely to occur, hydrogen sulfide, ubiquitous in the natural environment under anaerobic conditions, combines with mercury to form insoluble mercuric sulfide. Thus, under aerobic conditions in fresh water, methylation rates are likely to be higher than under anaerobic conditions, where the formation of mercuric sulfide binds mercury and hinders methylation (46).

5.1.2.2.5 Excretion of Inorganic Materials

General treatment of this subject is found in Table 5-10 and the discussion of this table.

DeFreitas and coworkers (47) studied the clearance rate of methyl mercury in fish. They found that the clearance rate (R) was related to body weight (W) raised to a power of -0.58 by the equation:

$$R = kPW^a$$

where k is the clearance coefficient, P is the body burden of pollutant, and a is the exponent of body weight for clearance having a value of -0.58. Clearance data from a number of fish species fit this relationship, and it may be reasonable to conclude that the value for a is not highly species specific. The value of k for methyl mercury of 0.029 per day for a fish of body size equal to 1 g (wet) would also appear to be not very species specific. When this clearance constant was used in a model for the bioaccumulation of methyl mercury in fish, a close fit was obtained between simulated and measured levels of methyl mercury in a population of yellow perch. This gives a biological half-life of methyl mercury of 50 to 500 days.

The general form of this equation may be applicable to other metals. Metals in general have biological half-lives in the range of 50 to 500 days (34,47).

5.1.2.2.6 Organics

The following section will contain a generalized summary of uptake, metabolism, and excretion of several key contaminant categories including phenols, polynuclear aromatic hydrocarbons (PAH), alkanes, alkenes, and aromatic hydrocarbons. A major portion of the discussion, however, will focus on PAH, their carcinogenic potential being a primary environmental concern.

Phenols have a high water and low lipid solubility and as such, would not be expected to accumulate in organisms. The simpler phenols are readily taken in and degraded by microorganisms, the primary mechanism of phenol degradation. Other organisms also absorb phenol from their aquatic environment, with little or no accumulation above ambient levels. Bioconcentrations more than 10-fold above ambient levels would be unexpected. Trophic biomagnification through the food chain has not been reported and would not be expected (20).

In aquatic environments, PAH are taken up and accumulated by organisms at rates that have been shown to be species dependent. It has been demonstrated that fish accumulate benzo(a)pyrene when exposed, reaching maximum levels of accumulation within an hour (48). Another study showed that fish and shrimp accumulate naphthalenes very rapidly; tissue concentrations often reach maximum levels within an hour after exposure. However, fish tissue levels usually begin to decline after the first hour of exposure (49).

Marine molluscs, on the other hand, tend to accumulate PAH more slowly over longer exposure periods. Although invertebrates tend to accumulate PAH from their surroundings and to release them unchanged in a relatively PAH-free environment, bioaccumulation factors ranging between 2 and 1,100 have been observed. Bioaccumulation appears to correlate directly with the PAH molecular weight, the lipid content of the organism, and inversely with rates of excretion. Like other hydrocarbons, PAH storage in tissues is directly related to the tissue lipid content.

The primary pathway of incorporating PAH into the food chain is believed to be through a surface adsorption mechanism (for example, via gills) rather than through an ingestion mechanism. However, the observed tendency of PAH to accumulate in biota in increasing concentrations with each progressive trophic level, indicates that consumption is a possible mechanism of PAH incorporation into the food chain (50). It has been suggested that ingestion of PAH-contaminated seafood could transfer the PAH to higher levels of the food chain. PAH accumulation by organisms that constitute the base levels of the food chain may have far-reaching effects throughout the food web. Tubifex worms were demonstrated to absorb and concentrate benzo(a)pyrene (BaP) without being able to metabolically degrade the PAH. Without such a detoxification mechanism in the worms, the PAH could be transferred to organisms feeding on the tubifex (51). The possibility that PAH may continue to concentrate in progressively higher levels of the food chain, eventually being transferred to humans, requires further study.

In natural waters, both the soluble and particulate forms of PAH remain quite stable. Microorganisms are capable of degrading various PAH, although the use of biological treatment to reduce PAH concentrations is not very effective in sewage treatment plants. Activated sludge treatment of domestic sewage was unable to effect significant removal of PAH by oxidation within normal detention times. Reduction of PAH in the sewage was attributed to adsorption by activated sludge.

Soil microflora can degrade PAH. Laboratory studies on BaP have shown that the degree to which bacteria can degrade BaP depends upon the species of organism as well as other environmental conditions such as the concentration of PAH compounds.

PAH are readily metabolized by fish, crabs, and zooplankton. Shellfish, however, are unable to degrade these compounds, indicating that PAH may accumulate in the tissues of oysters, clams, and other edible shellfish.

It has been observed that PAH is accumulated by mussels inhabiting polluted environments. However, when the mussels were transferred to relatively unpolluted environments, diminution of PAH content in all tissues was observed.

Plants have the ability to absorb PAH from water, air, and soil by roots and foliage. Roots can solubilize organic matter and absorb and translocate PAH compounds (with possible simultaneous concentration) to other parts of the plant, thus bringing these compounds into the ecological food chain (52). Plants appear to be capable not only of absorbing BaP but also of metabolically breaking it down for use in other compounds.

Humans take in or absorb PAH through various media. In industries generating atmospheric PAH, inhalation of particulates would be considered a primary mode of intake. In a coal liquefaction facility, exposed workers would probably inhale or absorb PAH as a vapor, an aerosol, or as molecules adsorbed on particulate matter in air. Although the general population is likely to encounter PAH via ingestion of contaminated food or drinking water, inhalation would probably be the most significant route of PAH uptake for people living near an emission source. Particles having a diameter of 5.0 microns are in the "respirable size range," that is, the size range most likely to be deposited in the pulmonary portion of the respiratory tract. As shown in Figure 5-8, 60 percent of all particulate matter in the size range of 0.5 to 2.0 microns that is inhaled is retained in the lungs, with the highest retention, 77 percent, occurring at 1.0 micron.

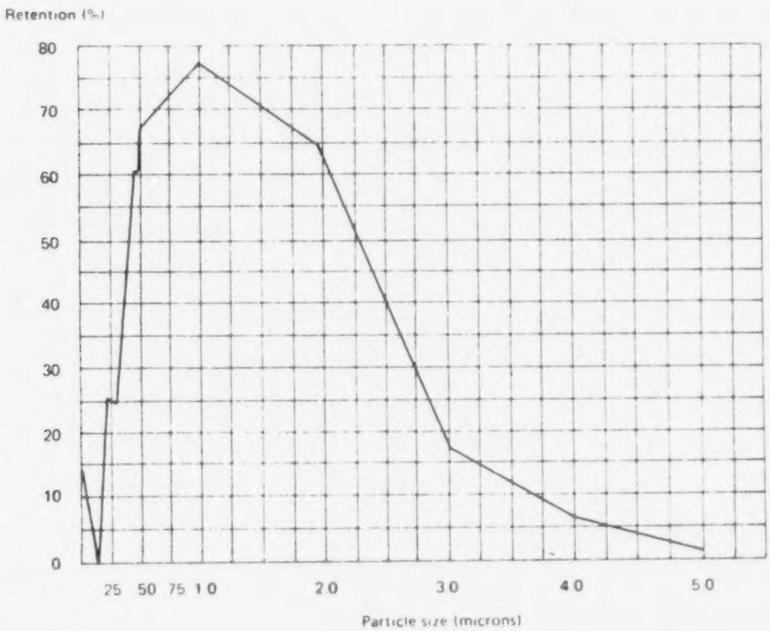

Figure 5-8. Retention of particulate matter in lung in relation to particle size (53)

Absorption of PAH through the skin is also significant as an uptake pathway. Topical applications of PAH dissolved in solvent applied to the skin of mice has resulted in systemic effects such as changes in blood, spleen, lymph nodes, and bone marrow.

5.1.3 Potential Ecotoxicological Effects of Chemical Pollutants

5.1.3.1 Ecotoxicological Effects of Specific Compounds

The potential hazard of contaminants discharged during the construction and operation of an SRC facility is dependent upon the composition and quantity of the contaminant, its environmental fate (transport, degradation, bioaccumulation, etc.), and its acute and chronic effects on organisms in the ecosystem.

The SAM/IA analysis is a methodology, explained in Appendix I of this report, by which the potential hazard of pollutants in waste streams is estimated. The SAM format directs the focus to each separate waste stream, allowing the quick identification of possible problem areas (or streams) where expected pollutant levels exceed the MEG. The significance of the SAM/IA analysis, however, is difficult to determine at this time because the hazard presented by the toxic unit discharge sum is obscure.

Using SAM/IA methodology, the relative hazard of each waste stream (as well as the combined discharge) is indicated by an assigned numerical value. Tables A-V-12 and A-V-13 of the Appendix provide examples of Level 2 SAM/IA analysis of waste streams emanating from the SRC plant. The concentrations of the pollutants used in the calculations were those listed in various tables in Chapter 3. Pertinent MATE values are reported in Appendix II.

The following section will address the toxic and carcinogenic aspects of specific compounds or compound groups. The hazard presented by these compounds may take such forms as subacute toxicity, acute toxicity, chronic toxicity, carcinogenicity, mutagenicity, and teratogenicity.

Where sufficient data are available regarding the quantity of a specific contaminant discharged or emitted, and its fate in the environment, its potential ecotoxicological impact may be estimated.

5.1.3.1.1 Inorganics

The pathological effect of several elements is shown in Tables 5-11 and 5-12. In these tables, a plus sign (+) indicates that the effect is observed. A minus sign indicates that the effect is not observed. A blank space indicates that no information is available. It is hoped that the blank spaces can be filled in as more information becomes available. In general, inclusion in these tables indicates that a particular element and/or their compounds or complexes should be of environmental concern. A system that attempts to rank the absolute toxicities of these elements based on these tables (the "Hittman Ranking Number") is discussed in Appendix V. Using this system, the elements were then ordered according to their relative hazard potential. This order is: sulfur as hydrogen sulfide, aluminum, iron, nitrogen as nitrate/nitrite, nitrogen as ammonia, potassium, titanium, magnesium, zinc, barium, boron, lead, manganese, nickel, fluorine, strontium, chromium, vanadium, copper, arsenic, cadmium, molybdenum, germanium, cobalt, selenium, gallium, beryllium, uranium, antimony, thallium, mercury, and finally tungsten. This ranking system thus rates the relatively innocuous elements such as aluminum and iron quite high on the list.

TABLE 5-11. SYNDROMES PRODUCED ON NON-HUMAN ORGANISMS BY VARIOUS TOXIC ELEMENTS

Element	Reduces animal growth	Affects mucous secretions of fish	Tetratogenic	Affects glands	Cardiovascular pathology	Affects nucleic acids	Lesions of the brain and spinal cord	Irritates mucous membrane	Hepatic lesions	Decreased learning ability	Cumulative	Affects mitochondra	Eye pathology	Chromosome damage	Carcinogenic potential	Affects fish's ability to regulate water balance	Adverse effect on reproduction	Cocarcinogenic potential	Pulmonary pathology	Hypertension	Renal pathology	Skin pathology	Skeletal pathology	Dental pathology	Gastrointestinal pathology	Shortens life span	Weight loss	Blood pathology	Interference with enzyme systems	Greater percentage of protein/animal	GOT activity stimulated	Gill damage	Abnormal behavior	Mutagenicity	Skeletal muscle pathology	Reticuloendothelial system pathology	React with SH groups of proteins	Interferes with immunological action	Reference*
Antimony			-		+		+														+				+	+	+	+	+				+	+	+	+	+		A
Arsenic			+		+	+	+		+				+				+				+		+		+		+	+		-	-		+		+		+		A–C
Beryllium	+			+		+			+						+		+		+		+		+			+	+	+					+						A,H–M
Cadmium	+		+	+	+		+		+		+	+		+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	A,B,N–S
Chromium															+		+	+	+		+						+	+		+	+			+					A
Cobalt															+												+			+	+			+					A
Copper	+		+		+		+		+		-		+		+	+	+		+		+	+			+	+	+	+	+	+	-		+				+		A,T–W
Fluorine																			+									+											X
Iron															+			+									+			+	-			+					A
Lead	+		+	+	+	+	+			+	+			+	+		+		+		+		+				+	+	+	+	+		+	+				+	A,B,O,Y–J'
Manganese							+																					+											K'
Mercury			+		+	+	+			+	+	+			+		+	+	+		+				+		+			+	-		+	+			+		A,M,P,L'–N'
Nickel	+		+	+	+		+						+		+		+		+		+	+			+		+		+	+	-			+		+		+	A,O'–R'
Nitrate/Nitrite	+				+														+																				T'
Selenium			+				+	+	+		+				+		+		+		+	+	+	+	+		+	+	+				+		+	+	+	+	A,B,U'
Thallium			+		+		+		+								+		+		+	+			+		+	+		+			+		+	+	+		A,V'–A"
Zinc	+	+		+	+				+				+				+				+		+				+	+	+	+	+		+	+		+	+	+	A,B",C"

(continued)

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TABLE 5-12. SYNDROMES PRODUCED ON HUMANS BY VARIOUS TOXIC ELEMENTS

Element	Brain and Nervous System Pathology	Pathological Blood Changes	Carcinogenesis	Reticuloendothelial System Pathology	Weight Loss	Chest Pain	Eye and Respiratory Tract Irritation	Chromosomal Alterations	Shortened Life Span	Alopecia	Adverse Effect on Reproduction	Skin Pathology	Cardiovascular System Pathology	Renal Pathology	Interferes with enzyme action	Pulmonary Pathology	Vascular System Pathology	Hepatic Pathology	Glandular Pathology	Skeletal Pathology	Gastrointestinal Pathology	Muscle Pathology	Dental Pathology	Hypertension	Headache	Nausea	Behavior Changes	References[a]
Antimony					+							+				+					+				+	+		A
Arsenic	+	+	+[a]	+			+					+			+	+	+?	+			+				+	+	+	A-J
Beryllium	+	+	+		+	+	+					+				+		+	+	+	+							A
Cadmium	+	+	+		+			+	+			+	+	+	+	+		+		+	+			+			+	A,K-Q
Chromium			+[a]		+		+					+									+							A,R-T
Cobalt			–																									A
Copper							+					+														+		U-W
Fluorine							+					+			+					+			+					A,X
Hydrogen Sulfide	+						+						+		+											+	+	Y
Iron			+																									A
Lead	+	+									+			+	+				+	+	+						+	A,Q,Z-D^{1}
Manganese	+		+										+			+											+	E^{1}
Mercury	+	+					+							+	+		+				+	+	+	+	+	+	+	A,Q,F^{1}-H^{1}
Nickel	+		+			+	+					+				+					+					+		A,I^{1}
Nitrate		+																								+	+	J^{1}
Selenium	+						+			+		+			+	+					+		+					A
Thallium	+	+								+		+	+	+		+		+			+	+				+	+	A,K^{1}-V^{1}
Vanadium							+										+											A
Zinc																					+							A

[a] Not found in animals models, however.

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Unfortunately, the validity of this ranking will have to be determined in the environment after the SRC plant has been in operation. However, these values do suggest areas which should not be overlooked.

5.1.3.1.2 Organics

The organic constituents in air emissions have not been quantified and can only be roughly estimated.

5.1.3.1.3 Airborne Contaminants

A major organic pollutant category present in SRC air emissions is that of PAH produced during combustion of coal for steam generation. These compounds are formed during combustion and will, upon cooling, condense out as discrete particles or condense onto the surface of existing particles. Atmospheric PAH is believed, therefore, to be almost exclusively associated with particulate matter (27). PAH concentrations in fly ash collectors at two coal-fired power plants are shown in Table 5-13. The first seven compounds are of interest in that several are considered carcinogenic. Hence, control technology which is effective in reducing particulate emissions will also significantly reduce PAH emissions.

The primary ecotoxicological concern with PAH is the carcinogenic propensity of many of these compounds, as shown in Table 5-14. Acute and chronic toxicity are of lesser concern, the systemic acute dose of LD_{50} (the lethal dose for 50 percent of animals tested) being extremely high compared to the dose necessary to produce carcinogenic effects.

TABLE 5-13. POLYNUCLEAR HYDROCARBON CONCENTRATIONS IN FLY ASH FROM COAL-FIRED POWER PLANTS A AND B (Micrograms/10^6 kJ Input) (18)

Compound	Unit A*										Unit B
	Full load		Full load		Full load		Partial load		Partial load		Test no.3 full load
	b	a	b	a	b	a	b	a	b	a	a
Fluoranthene	380	na	190	211	na	200	338	401	1583	90	232
Pyrene	148		137	190		127	190	232	833	72	127
Benzo(a)pyrene	53		23	19		19	60	54	422	127	19
Anthanthrene	17								34		
Benz(a)anthracene						39	49			106	
Benzo(ghi)perylene							20		158	80	
Benzo(e)pyrene							35	40	243	76	
Coronene									4		
Anthracene									101		
Phenanthrene									781	21	
Perylene									63	3	

b = before fly-ash collectors. a = after fly-ash collectors.

[na] No analysis due to loss of sample. A blank indicates that the component was not detected in the sample.

* Units A and B produced 1 x 10^6 pounds steam at 1900 psi and 1000°F, coal-fired power plant.

**A and B refer to operating steam generating units.

TABLE 5-14. ADVERSE EFFECTS FOR SELECTED ORGANIC COMPOUNDS POTENTIALLY EMITTED BY LIQUEFACTION PLANTS (18)

Compound	Acute toxic effect	Carcinogen	Reticuloendothelial system pathology	Gastrointestinal pathology	Reproductive system pathology	Hepatic pathology	Renal pathology	Respiratory system pathology	Hormonal pathology	Cocarcinogen	Mutagen
7, 12-Dimethylbenzo [a]anthracene	+	+++	+	+	+						+++
Benzo[a]pyrene	±	+									- or +
3-methylcholanthrene	±	+	+			+	+	+	+		-
Anthracene	-										
Dibenzo[a,h]anthracene		+									
n-dodecane		-								+	
Dodecylbenzene		-								+	
Decahydronaphthalene										-	
1-dodecanol										+	
1-phenyldodecane										+	
Phenols										+	
Formaldehyde										-	
Furfural										+	
Benzo[e]pyrene		-									-
3-hydroxybenzo[a]pyrene		-									±
Dibenzo[a,c]anthracene		-									-
Dibenzo[a,h]anthracene		±									±
B-naphthylamine		+									
Isophorone			+				+				
Benzene			+								
Ethylbenzene											
Acenaphthene							+				

The carcinogenic potential of many PAH compounds has been widely demonstrated in laboratory animal studies using specific PAH compounds as well as complex mixtures of compounds such as coal tars, product oil, and fly ash. The PAH, along with other compounds potentially produced during the liquefaction process that are known or suspected to be carcinogenic, mutagenic, or teratogenic, are shown in Table 5-15. The EPA-NIOSH adjusted ordering numbers (reflecting the size of dose in relation to the carcinogenic response) of various carcinogenic compounds are shown in Table A-II-1. The significance of these ordering numbers is discussed in Appendix II.

A difficult problem in all bioassays is the extrapolation of data from experimental animals to man. Marked differences in susceptibility to carcinogenic agents exist between species as well as between strains of the same species. For example, the site of origin and the histologic type of respiratory tract tumor depend on the species and strain of animal as well as the route of application and dose. Dose levels in animal experiments considerably exceed the natural levels experienced by humans. Furthermore, the artificial laboratory system does not allow for the interactions and synergisms that occur in the natural and work environment. The role of cocarcinogens is obviously important. This is illustrated by the fact that PAH carcinogenesis is enhanced in animals by exposure to PAH in the presence of chemicals such as iron oxides and long-chain aliphatic hydrocarbons, or is inhibited by materials such as Vitamin A and selenium (18).

The problem of assessing the carcinogenicity of inhaled substances is, in addition, complicated by other factors. The concentration and physical state of damaging elements at the human receptor site have not been adequately established;

TABLE 5-15. KNOWN OR SUSPECTED CARCINOGENS WHICH MAY BE IN THE EFFLUENT STREAMS OF COAL LIQUEFACTION PLANTS (18)

Compound Type	Example
bicyclic compounds	benzidine
nitrosamines	
nickel	nickel carbonyl
chromium	chronic trioxide or chromate salts
beryllium	beryllium oxide
arsenic	tricalcium arsenate
selenium	selenide sale
cobalt	cobalt sulfide
lead	lead chromate
zinc	zinc chromate
mercury	elemental mercury
cadmium	cadmium sulfide
anthracenes	anthracene and 9,10-dimethylanthracene
chrysenes	5-methyl cystein
benzanthracenes	benzo(a)anthracene
fluoranthene	benzo(j)fluoranthene benzo(b)fluoranthene
cholanthrenes	20-methylcholanthrene
benzopyrenes	benzo(e)pyrene and benzo(a)pyrene
dibenzpyrenes	dibenzo(a,l)pyrene, dibenzo(a,n)pyrene, dibenzo(a,i)pyrene, dibenzo(a,h)pyrene
mono- & dibenzacridines	dibenz(a,h)acridine
benzocarbazoles	7H-benzo(c)carbazole
dibenzocarbazoles	7H-benzo(c,g)carbazole
benzanthrones	benzo(a)anthrone and 7H-benz(d,e)xanthracene-7-one
aminozobenzenes	4-dimethylaminoazobenzene
acenaphthenes	acenaphthene
naphthylamines	alpha-naphthylamine beta-naphthylamine
fine particulates	sulfur, coke
amines	diethyl amines methylethyl amines
monoaromatic	benzene
pyrenes	cyclopenta(c,d)pyrene indeno(1,2,3-c,d)pyrene

there is compelling evidence that carrier substances are important, but their exact role can only be surmised. Also, the assumption that lung tumors are the consequence of a single pollutant is almost certainly wrong, and there is much to support the idea of synergism or cocarcinogenesis (27).

Benzo(a)pyrene is frequently taken as the primary index of air pollution, with the recognition that it is only one of the polycyclic organic materials in the air. Its selection as an index is plausible for several reasons: it appears in solid form in air, is usually adsorbed on particles, and therefore can be filtered and collected. It is also relatively easy to measure and is well correlated with other polynuclear aromatics. It has been found to be carcinogenic in animals, and it is suspected of being carcinogenic in man (27).

The carcinogenicity of PAH in mammals is almost exclusively limited to 4-, 5-, and 6-ring polycyclics and some methylated derivatives, although no definite structure-effect relationship has yet been determined. Moreover, the presence of N or S heteroatoms in basic polycyclic hydrocarbon structures has been demonstrated in different cases either to intensify or reduce carcinogenic effects. Because N- and S-containing polycyclic compounds are more water-soluble than the corresponding hydrocarbons, they may be present in effluents at greater levels than those of the polyaromatic hydrocarbons; their hazards in water may therefore equal or exceed those of non-substituted polycyclics (18). Further evidence of PAH carcinogenicity has been provided by epidemiologic studies of industrial workers exposed to high levels of PAH. Although the products of coal combustion, coking, petroleum refining, and coal pyrolysis are not identical to those of coal conversion, many compounds known to be carcinogenic have been found in all these products or their process streams.

In a recent study, risk to workers exposed to coal-tar-pitch volatiles (topside of the ovens averaged 3.15 mg/m^3) was a function of both exposure level and length of exposure. Lung cancer developed over a period of time varying from 10 to 40 years, with an average of 25 years. A threshold limit of 0.2 mg/m^3 for a period of 30 years did not increase the carcinogenic risk (54). This study, along with other epidemiologic studies, gives further supporting evidence of the potentially carcinogenic and hazardous nature of coal liquefaction products and process streams.

The constituents in coal liquefaction product oil are known to be carcinogenic and all contact should be avoided. Stringent controls should be exercised regarding fugitive emissions in the workplace. Analysis of product oil from coal liquefaction, as well as oils in coal tar and petroleum crudes, has revealed high levels of PAH compounds. Benzo(a)pyrene concentrations ranged from 40 to 50 ppm in the coal-derived products (18). Table 3-38 shows a general composition of product oil.

Laboratory animal studies have been performed to determine the carcinogenicity of liquefaction product oil. Several streams and products of the coal hydrogenation process were painted on the skin of mice to test their carcinogenic effect. The whole light-oil stream and eight individual fractions of this stream were all without tumorigenic action. The light- and heavy-oil combustion products were mildly tumorigenic, predominately producing papillomas. However, the streams boiling at higher temperatures, the middle-oil, light-oil stream residues, pasting oil, and pitch product were all quite carcinogenic. This carcinogenicity is quite possibly due to the polynuclear aromatic hydrocarbon level in the product oils (18). These laboratory studies, along with epidemiology studies of occupational exposure, give further evidence of the role of PAH in the production of skin cancer. However, the levels of exposure to carcinogens or cocarcinogens in industry are very different from those due to community air pollution. In most instances, the specific PAH has not been identified, nor has the importance of airborne transmission of the carcinogenic agent been considered in contrast with other routes of exposure.

The data do not allow the construction of any accurate dose-response relations. Although carcinogenesis may occur at a high level of exposure to a carcinogen or cocarcinogen, there is no information on the effect of clearly lower concentrations of chemicals, such as would be found in polluted community air.

No information was found to indicate that carcinogenic PAH affects vegetation. Polycyclic compounds adsorbed by roots from contaminated solutions, by foliage from polluted atmospheres, and by aquatic plants from contaminated bodies of water are added to the traces of these compounds produced metabolically in the plants (27).

Although a rough estimate has been made in Chapter 3 of the quantities of hydrocarbons emitted to the air, the lack of precise data on the type of compounds prevents any evaluation of the hazard potential of these compounds. The following discussion is confined to toxicity data regarding various hydrocarbon categories. At concentrations found in ambient air, hydrocarbons have rarely been observed to have direct physiological effects on humans or animals, although effects have been noted at higher levels.

In general, members of the aliphatic hydrocarbon series are biologically and biochemically inert; i.e., they produce no detectable functional or subclinical alterations. The lower members, with the exception of methane and ethane, are gases that tend to have anesthetic properties rather than toxic properties. This is particularly true of the unsaturated (olefin) compounds. Ethylene, propylene, and acetylene have all been used as anesthetics, and available evidence indicates that these gases are rapidly eliminated from the lungs in the unchanged state. No effects were reported for aliphatic compounds at levels below 1700 mg/m^3. Thus, these compounds must usually be present in relatively high concentrations before noticeable effects are produced (55). Other aliphatic hydrocarbons also do not tend to accumulate in body tissues; thus cumulative toxicity from repeated exposure to low atmospheric concentrations is improbable.

The aromatic hydrocarbons are biochemically and biologically active. The vapors are much more irritating to the mucous membranes than equivalent concentrations of the aliphatic group. Systemic injury can result from the inhalation of vapors of the aromatic compounds, and hematological abnormalities, including leukemia, are associated with chronic benzene inhalation. No effects, however, have been reported at levels below 25 ppm (55).

One environmental concern with regard to hydrocarbons in general is the tendency of some to participate in photochemical reactions and contribute to smog conditions. The present state of knowledge does not demonstrate any direct effects on human populations of the gaseous hydrocarbons in the ambient air, although many of the effects attributed to photochemical oxidants are indirectly related to ambient levels of these hydrocarbons. In smog formation, the quantity of eye irritants formed is a reflection of the hydrocarbon precursors in combination with oxides of nitrogen. Table 5-16 gives a ranking of the eye irritation potency of various hydrocarbons in irradiated synthetic atmospheres.

TABLE 5-16. EYE IRRITATION POTENCY OF VARIOUS HYDROCARBONS IN IRRADIATED SYNTHETIC ATMOSPHERES (55)

Hydrocarbon	Potency[a]	Hydrocarbon	Potency[a]
n-Butane	0	m-Xylene	2.9
n-Hexane	0	1,3,5-Trimethylbenzene	3.1
Isooctane	0.9		
tert-Butylbenzene	0.9	1-Hexane	3.5
Benzene	1.0	Propylene	3.9
Ethylene	1.0	Ethylbenzene	4.3
1-Butene	1.3	Toluene	5.3
Tetramethylethylene	1.4	n-Propylbenzene	5.4
cis-2-Butene	1.6	Isobutylbenzene	5.7
Isopropylbenzene	1.6	n-Butylbenzene	6.4
sec-Butylbenzene	1.8	1,3-Butadiene	6.9
2-Methyl-2-butene	1.9	α-Methylstyrene	7.4
trans-2-Butene	2.3	Allylbenzene	8.4
o-Xylene	2.3	β-Methylstyrene	8.9
p-Xylene	2.5	Styrene	8.9

[a] Conditions: Hydrocarbon 2 ppm, nitric oxide 1 ppm for all except styrene, α-methylstyrene, β-methylstyrene, and allyl benzene (for those, hydrocarbon was 1 ppm, nitric oxide 0.5 ppm).

5.1.3.1.4 Water

The waste streams containing the major organic compounds are those produced by the liquefaction process rather than the auxiliary facilities. The foul water condensate is viewed as the process waste stream containing the heaviest organic loadings and potentially the greatest environmental hazard if directly discharged to the natural waterways. The SRC design plans indicate that there is a possibility that this wastewater stream and other process wastewater streams will be continually treated and recycled. However, assuming the situation in which wastewaters are discharged rather than recycled, the indications are that treatment schemes may be available to produce an effluent of acceptable quality. The following discussion of process wastewater constituents will be an attempt to assess the hazards of the situation in which the wastewater is discharged rather than reused.

The organic compound groups that are known or suspected to be in process wastewater are the following: phenols, polynuclear aromatic hydrocarbons, polycyclic N-aromatics, polycyclic hydroxy compounds and straight-chain hydrocarbons (Chapter 3). Evaluation of the hazards of these compounds is complicated by the fact that quantified levels of these compounds in SRC wastewater are limited or nonexistent. In addition, information on the environmental fate and ecotoxicological effects of many of these compounds is also very limited at this time.

In situations where analysis has not been performed on SRC wastewater, data from similar conversion processes will be utilized to give a general approximation of potential pollutants. Obviously, actual quantification of SRC wastewater before and after treatment would provide a much more reliable mechanism for assessing the potential hazard of the waste streams.

5.1.3.1.5 Phenols

Phenols are the major organic constituent in the foul process condensate, ranging in concentration from 5,000 to 12,000 mg/l. They constitute 47 to 64 percent of the COD in foul water condensate from liquefaction processes, compared with 68 percent in the condensate from coking plants (Chapter 3).

The lowest concentration of phenol shown to be toxic to any organism was 10 μg/l. At that level, the green algae (Chlorella vulgaris) grew abnormally during chronic exposure. There is not, however, enough chronic toxicity or metabolic data to generalize about the effects on algae. Certainly, aquatic plants are more endangered than terrestrial, but no specific populations can be shown to be adversely affected by phenol in the environment. A level of 2 mg/l inhibited oxygen consumption in a freshwater snail, (Helisoma tuvolis) (18).

Short-term toxic concentrations for freshwater fish are in the range 10 to 40 mg/l with sublethal effects (altered serum enzyme activities were observed) in pike (Esox lucius) exposed to 5 mg/l. Reproductive effects have not been adequately evaluated. No assessment of risk to populations is presently possible (18).

Concentrations of 1 to 10 mg/l in water results in the tainting of fish flesh. Human ingestion of 14 mg/kg has resulted in gastrointestinal effects, and ingestion of 140 mg/kg was reported to cause death to a human (1).

Phenolic compounds are readily degraded by standard biological treatment to low discharge levels. Utilizing various standard treatments, as discussed in Chapter 3, it is projected that phenols could be reduced to levels in the range of 0.3 to 3.0 mg/l. Although biological treatment may not be sufficient to reduce the phenols to lower levels, additional treatment such as carbon adsorption could probably be used to reduce phenols sufficiently to meet stringent standards. To date, EPA effluent guidelines have not been established for coal liquefaction facilities, although they have been established for the by-product coking industry (0.0006 kg phenol/Mg product - daily maximum) and for the petroleum refining industry, subcategory topping (0.088 kg phenol/km^3 of feedstock - daily maximum) (Chapter 3). The MEGs for phenol are 5 μg/l based on health effects and 500 μg/l based on ecological effects.

The liquefaction foul water condensate has not been fully quantified but may contain compounds which are more resistant to degradation and standard waste treatments than are the phenols. The lack of information about the composition of the condensate, as well as the degradation paths and rates of the various constituents, increases the difficulty of predicting the effectiveness of foul water treatment. Quantitative analysis of the foul water condensate before and after various treatment procedures could provide key information about the rates at which various compounds are degraded and removed from the environment. Analysis of any solid waste generated and of air emissions would be needed to verify whether the compounds in question were actually degraded or just transferred to another media.

5.1.3.1.6 Bio-Pond Sludge

The bio-pond produces only a nominal 27 Mg per day, compared to the total volume of 14,000 Mg solid waste generated by a conversion plant. However, the presence in the bio-pond of phenols, ammonia, cyanides, COD, thiocyanates, and other potent wastes makes imperative the proper disposal of the sludge. Once formed and removed from the pond, the sludge will contain coal tars, sand, coal fines, and biotreatment by-products. Prior to disposal, it will probably be de-oiled by dissolved air flotation (possibly accompanied by an API separator) and either air-dried or centrifuged (18).

Phenols are high in acute toxicity but are low both in deleterious chronic effects and bioaccumulation potential. The relatively high efficiency of the removal of simpler phenols by wastewater treatment procedures and their rapid degradation by microbial systems, may result in the environmental concern being directed toward the more complex and less degradable phenols.

The synergistic potential of phenols is uncertain. Although additive interactions have been demonstrated between phenol mixtures, metals, ammonia and phenol, and mixtures of ammonia, phenol, zinc, copper, and cyanides, other studies have yielded contradictory results (54). The significance of phenol potentially functioning as a co-carcinogen should not be overlooked. Phenol is included in the NIOSH list of suspected carcinogens, although there is no specific evidence of human cancer attributable to phenol (1).

The EPA-NIOSH ordering number of 3121 for phenol, together with the large dose administered, yields an adjusted ordering number of 0.78. The significance of a compound with such a low adjusted ordering number as a cancer-inducing agent is highly questionable. Additional studies utilizing mixtures of phenol and other suspected carcinogenic agents, could better document the co-carcinogenic potential of phenol and perhaps elevate its importance in terms of carcinogenicity.

5.1.3.1.7 Polynuclear Aromatic Hydrocarbons

PAH have been found in small quantities in raw process wastewater. Table 3-17 shows quantified values for foul-water condensate from the SRC-I mode, using Kentucky high-sulfur bituminous coal. Although an environmental concern because of their carcinogenic potential, the low levels of PAH found in the process wastewater are below those levels considered hazardous. Even prior to wastewater treatment, the PAH levels are 1 to 6 orders of magnitude below the MEG values based on health effects. Table 5-17 lists the toxicity of PAH compounds to several aquatic organisms.

Very limited information is available regarding the low-level chronic or sublethal effects of PAH. Many of the available studies have focused on the long-range effects of oil spills and other petroleum pollution, but the extent of the PAH effect is not discernible from these studies. Although contaminants at very low concentrations may cause no direct mortality to individual organisms, entire populations and natural communities may be adversely affected (56).

Biodegradation of PAH is expected to be highly variable and cannot be depended upon to reduce the level of any one particular compound in the effluent streams. For the purpose of estimating PAH levels after wastewater treatment, a 30 to 80 percent degradation was assumed (see Table 3-17). Also, the oxidation of any one of these compounds does not necessarily mean that the carcinogenic activity has been reduced; metabolic oxidation of PAH in other systems has been known to both increase and decrease the carcinogenic

TABLE 5-17. AQUATIC TOXICITY OF PAH (18)

Organism	Method	Chemical used	Temp. (°C)	Exposure time (hours)	Dose administered	Number of deaths	Within	Effects Produced	Within
Rana pipieas (Leopard frog)	Injection into kidney	3,4-benzpyrene	14-16°	Single dose	0.3-0.5 mg	15/15	5 days		
		5,7-dimethyl-1,2-benzanthracene			0.3-0.5 mg	8/8	5 days		
		3-methylcholanthrene			0.3-0.5 mg	6/6	5 days		
		p-aminoazobenzene			0.3-0.5 mg	20/59	3 weeks	adeno-carcinoma in 23%	3 wks-7 months
		1,2,5,6-dibenzanthracene			0.3-0.5 mg	13/36	3 weeks	adenocar. in 26%	3 wks-7 months
Bufo arenacum (Toad)	Implantation into tail subcutaneously	20-methylcholanthrene		Single dose	Not given (crystals)			Super-numerary fins in 1/38	16 days
		3,4-benzpyrene		Single dose	Not given (crystals)			Sup. fins in 1/62	26 days
		7,12-dimethylbenz(a) anthracene		Single dose	Not given (crystals)			Sup. fins in 50/50	20 days
Lepomis macrochirus (Bluegill sunfish)	Flowthrough	benz(a)anthracene		6 months	1.0 ppm	87/100	6 months		
Paracentrotus libidus (Sea urchin)	Static	7,12-dimethylbenz(a) anthracene	18-20°	48 hours	1×10^{-7} to 1×10^{-4} M			Develop-mental abnormalities in 70-100%	48 hrs.
		benzo(a)pyrene							

potential. The effectiveness of various treatment methods in removing PAH and harmful degradation products from wastewater streams is an area in which research could provide pertinent information.

Ash from steam generation could also be a significant source of PAH. During combustion, PAH are produced and adsorbed to the particulate matter. Significant quantities of PAH would not, however, be expected to be associated with gasifier ash. Gasifier temperatures are sufficiently high to completely break down and destroy all organics, including PAH.

Both bottom and fly ash are slurried and piped to settling ponds. Because of the low water solubility, low volatility and strong adsorption to particulate matter, most of the PAH would be associated with the suspended particulate matter or sediments.

PAH concentrations in fly ash collectors at coal-fired power plants were shown previously in Table 5-13; the PAH are considered to be products of the incomplete combustion of coal. The first seven compounds are of interest in that several are considered to be carcinogenic (18).

PAH entering natural water systems will suffer decomposition, storage, or removal. In aquatic environments, decomposition is accomplished primarily through photooxidation, with biodegradation assuming a lesser role; storage is through consumption by biota or incorporation into sediments. Removal by physical transport may occur in the absence of degradation and bioaccumulation. Solubility is important in determining which aquatic interaction will prevail -- whether a hydrocarbon will go into solution, become suspended in the water column, or adsorb onto the sediments. However, mechanisms for hydrocarbon solubility, particularly PAH, are poorly understood and the data are incomplete and discordant (54).

The fate of PAH adsorbed to ash in settling ponds is not well known. Analysis of ash pond leachate has generally dealt with inorganics and ignored potential PAH contaminants. Quantification of PAH in ash pond leachate and/or overflow would provide additional information with which to further assess the environmental hazards of combustion ash. Composition of the ash pond constituents is affected by a number of factors including the coal type as well as the quantity and quality of water used in sluicing. Virtually nothing is known, however, of subacute interactions between compound classes at the low levels anticipated in effluents. Potential hazards could exist for both aquatic organisms and human populations exposed through either water consumption or ingestion of fish and shellfish. The scarcity of information on carcinogenic and mutagenic effects of heteroatomic polyaromatic compounds, the potential interactions between compound classes, and the complete absence of information on effects of trace levels of all polycyclic compounds to aquatic organisms indicate the urgent need for research in these areas (18).

5.1.3.1.8 Solid Wastes

The large quantities of solid waste generated by a coal liquefaction facility (in excess of 14,000 Mg/day) are a major concern with regard to the pollutants discharged in the form of fugitive emissions, runoffs, and leachates.

Secondary pollutants resulting from solid waste disposal may present the greatest environmental hazard with regard to operation of coal liquefaction facilities; however, only limited quantification studies of the potentially leachable pollutants have been completed. It is obvious that a top priority with regard to estimating solid waste hazards should be to quantify the various constituents both before and after treatment, and to assess the likelihood of these constituents leaching out and polluting the groundwater.

In considering the organic pollutants, solid wastes of primary concern include the bio-unit sludge, the steam generation ash (containing adsorbed PAH), and process residue. Although not yet characterized with respect to organics, the 0.50 to 0.62 Mg/day of bio-unit sludge would very likely contain toxic and volatile organics. The lack of characterization of this sludge hinders further evaluation of its hazard potential.

In regard to ash, the combustion ash from steam generation (approximately 102 Mg/day) is of major concern with regard to PAH. These compounds are produced during combustion and tend to condense on particulates (e.g., fly ash). The production of PAH seems to be a function of combustion conditions.

One factor influencing PAH formation is the temperature of combustion; there is an increase in PAH production with increasing temperatures. The high operating temperature of the Koppers-Totzek gasifier (1,850°C) is claimed to destroy all organic compounds (18). The gasifier ash would, therefore, not be expected to present the same hazard with regard to PAH compounds as that found with ash produced by the combustion of coal.

The SRC process residue contains large quantities of organic compounds. It would not, however, be a likely source of pollution because its high carbon content would make further energy extraction highly desirable. Certain gasifiers are able to utilize the residue, deriving additional heat value and leaving behind an inorganic ash.

Although it is unlikely that the process residue will be disposed of without recovery treatment (such as gasification), in the event that this is not the case, an assessment should be made of the potentially leachable contaminants. Table 3-32 shows the several organics quantified to date in the residue. In an effort to determine the leachability of the residue, an unsuccessful attempt was made during the test period to dissolve the solid in dilute acid (Chapter 3).

5.1.3.2 Special Ecotoxicological Considerations

Ecotoxicological effects of substances of environmental concern which are based solely on laboratory-determined toxicity data (such as LD_{50}) may be inapplicable to environmentally significant situations. Unfortunately, the most meaningful experiments are difficult to conceptualize, time consuming, and expensive. Therefore, most of the data base which is being used to determine the environmental hazard of a compound, including the MEGs, is comprised of short-term toxicity studies.

There are several reasons why laboratory-determined toxicity data may not reflect the actual environmental hazard. The organism most sensitive to a particular substance may not be tested; yet the loss of this single species may result in a "domino" effect which could promote considerable environmental imbalance and change. The physical or chemical form of the pollutant, or the route of administration of it, may differ from the exposure expected in the environment. There may be synergistic or antagonistic effects between pollutant substances which may mitigate or potentiate the effect. A substance which may be harmless when ingested may give off toxic fumes if it is burned or exposed to extreme heat. An innocuous substance may be transformed to an environmentally hazardous substance when exposed to sunlight. A substance harmless to one group of organisms may be metabolized by this group into a substance which is harmful to another group of organisms. Toxic concentrations of materials may be accumulated by certain plants or animals without apparent harm, but the animals which eat these organisms may suffer acute or chronic toxic symptoms. Nutritional factors also must be considered. For example, algae were reported to prefer ammonia over nitrate nitrogen as a nitrogen source.

5.1.3.2.1 Temperature Effects

Among the factors not considered in the MEG approach are temperature effects. A change in temperature can increase or decrease the toxicity of cadmium (57,58,59,60), chromium (57,58), copper (57,58,61), lead (57,58,62,63,64, 65), mercury (57,58), nickel (57,58,66), and zinc (57,58, 67,68,69,70,71). The direction and magnitude of the effect depend on species and other conditions. A temperature increase may increase the metabolic rate of aquatic organisms, which may transform the toxicant to a more toxic or less toxic form, aid excretion of the toxicant, or aid transport of the toxicant to sensitive tissue or organ systems.

5.1.3.2.2 Toxicity Differences Related to the Oxidation State or Form of Elements

The MEG approach does not completely account for toxicity differences due to the particular elemental form. All forms of an element may not have been tested; consequently, the most toxic form of the element may not have been tested. On the other hand, MEGs based on the most toxic form of the element may overestimate the possible environmental effect.

Estimation of the importance of this effect is complicated by the lack of research on the possible differential toxicities of elemental forms. However, it is known that trivalent forms of antimony are more toxic than pentavalent forms (20). Arsines (trivalent inorganic and organic) are more toxic than inorganic arsenites; the latter are more toxic than arsenoxides (trivalent with two bonds joined to oxygen). In turn, arsenoxides are more toxic than arsenates (inorganic); the latter are more toxic than pentavalent arsenicals (such as arsonic acids). Arsonic acids are more toxic than arsonium compounds (four organic groups with a positive charge on arsenic), and the latter are more toxic than elemental arsenic (72,73,74,75,76,77,78). Hexavalent chromium compounds are more toxic than trivalent ones (79). Organic forms of mercury are more toxic than inorganic forms, perhaps because the organic forms are more easily taken up by living systems (79). Soluble selenium salts are more toxic than elemental selenium (72). Vanadium toxicity increases with the valence, with the pentavalent state being the most toxic (79). A further complication to the estimation of the importance of this effect is that the form and oxidation state of the element can be changed by environmental forces. As discussed previously, the toxicity of elemental mercury can be quite significantly increased by microbial methylation.

5.1.3.2.3 Water Hardness as a Factor in Determination of the Toxicity of Inorganic Substances

A number of studies have shown decreased trace element toxicity in fresh water with increased hardness. Reduced toxicity in hard alkaline waters is best explained by a decrease in the uptake of the toxic trace element. Physiochemical factors influencing the bioavailability of trace elements in such waters include (1) precipitation of insoluble hydroxides, carbonates, and hydroxy-carbonates; (2) the formation of inorganic solute complexes with carbonate, hydroxide, phosphate, or sulfate; and (3) competition between alkaline earth cations and trace elements for membrane transport sites. The literature does not provide definitive information as to whether the hardness (calcium and magnesium) or the increased alkalinity that commonly accompanies increased hardness, is the important factor.

Inorganic speciation may also be important in determining the bioavailability of metals in seawater. A decline in biotic uptake of metals with increasing salinity in estuaries has been reported by a number of authors. Decreased trace element bioavailability with the increased dominance of inorganic complexes in seawater may contribute to such results. Complexation of vanadium with oxyanions such as phosphate or arsenate, may decrease uptake of this metal by marine tunicates (61).

5.1.3.2.4 Organic Complexes as a Factor in Determination of the Toxicity of Inorganic Substances (61)

The extent to which organic complexation of trace elements occurs in natural waters and the bioavailability of the organic complexes relative to the inorganic forms are important questions. With some exceptions, organic complexation usually reduces the bioavailability of trace elements. Chelation with ethylenediaminetetraacetic acid (EDTA) reduced the toxicity to algae of copper and zinc. The toxicity of copper in highly organic sulfate liquor wastes from pulp mills was found to be considerably less than its toxicity in fresh waters. Natural organics, extracted with seawater from either soil or sewage, reduced the toxicity of copper to both copepods (zooplankton) and benthic invertebrates. The toxicity of copper to algae increased in the following order: copper-EDTA, copper citrate, and Cu (II). Complexation of mercury with glutathione reduced the toxicity of this metal to the crustacean *Artemia*. The accumulation of mercury by benthic invertebrates was reduced by 20 to 80 times by complexation of solute with cysteine or protein. The addition of 2 mg per liter of cysteine hydrochloride decreased mercury uptake to nearly one-sixth of the original value in fathead minnows. These findings suggest that biotic accumulation of trace elements present at a similar total solute concentration, would be greater in waters where dissolved organics are less abundant (e.g., oligotrophic waters) than in waters where dissolved organics are more abundant (e.g., eutrophic waters).

On the other hand, some authors have suggested that organic complexation of solute trace elements may enhance their availability to biota. Increased trace element uptake through complexation may result from (1) a decrease in rate and extent of trace element sorption by sediments; (2) solubilization of solid forms of trace elements in soils and sediments; (3) a valence reduction and/or stabilization of the reduced valence state or vice versa; and (4) formation of physiologically active complexes. Terrestrial plants were found to accumulate much more gallium. indium, and chromium when these elements were added as water-soluble organic complexes than in the unchelated form. Organic complexation may be important in maintaining elevated concentrations of solute trace elements often observed in interstitial waters. However, such solubilization of trace elements does not necessarily enhance bioavailability. The addition of fulvic acids to soils (under greenhouse conditions) increased the amount of water-soluble selenium, but depressed selenium uptake by alfalfa plants. Similarly, the oxidation of dissolved organics with ultraviolet light was found to decrease algal growth in seawater. The original growth rate was totally reinstated by addition of EDTA to the water. In addition, the growth rate was partially restored by adding soluble iron and manganese. These results suggest that organic complexation reduces the rate of trace element conversion to solid forms of low bioavailability. Organic complexes may also attenuate the effects of excessive concentrations of trace elements. Moreover, an excess of organic complexing agents will reduce algal growth by decreasing the activity of essential trace elements below optimum levels.

The importance of these various effects is hard to determine because changes in the forms of the elements in the environment can occur. For example, zooplankton excrete organic complexes of zinc. Thus a biogenic source of organically-complexed trace elements may be present even where solute trace element and organic carbon levels are low. It has been found that the complexation quantities are similar to the concentrations of dissolved trace elements present in unpolluted surface waters. This permits the interpretation, but in no way proves, that trace elements in surface waters are largely transported in the form of soluble organic complexes.

5.1.3.2.5 Bioconcentration

Bioconcentration refers to the ability of an organism to accumulate a pollutant above the ambient level. This phenomenon may result from an energy-requiring, active transport mechanism by which the organism concentrates a micronutrient from the environment. However, the phenomenon also occurs if the pollutant is sequestered in the organism. This sequestration may result from chemical reactions (for example with protein sulfhydryl groups), physical transitions (for example, a lipophylic compound dissolving in high lipid tissue and thus removing itself from the aqueous excretion process), or biological substitution (strontium replacing calcium in bone). Higher aquatic organisms such as fish can incorporate arsenical compounds and metabolize them yielding high-molecular-weight lipid material (80).

Bioaccumulation can lead to the build-up of a toxic concentration of a substance in an organism over a period of time. This is one reason why acute toxicity experiments may not be applicable to prediction of possible adverse environmental effects. Because of this phenomenon, the use of acute toxicity experiments in methodologies (such as the MEGs) which attempt to predict the environmental impact of a substance or group of substances, may lead to underestimation of the possible effect and consequent overestimation of the concentration which will not have an adverse environmental effect.

Unfortunately, the bioconcentration factors are not constant even for a given substance for a given species. This makes this phenomenon hard to incorporate into treatments of possible environmental effects.

5.1.3.2.6 Synergism and Antagonism

Perhaps the best-known protective action is that of selenium against mercury toxicity. Selenium also gives some protection against cadmium and against liver damage by thallium in rats. Selenite is reported to protect human reproductive tissues and mammary glands against the hemorrhagic necrosis produced by cadmium, and it may also protect people against cadmium-induced hypertension. Ganther and coworkers have proposed that the protective effects of selenium arise from the complexation of mercury and cadmium by selenium in high-molecular-weight proteins within tissues. Such complexes divert mercury and cadmium from their toxicological target molecules (20,61).

Assimilation of the related element arsenic affords partial protection against selenium and mercury toxicity as indicated by (1) a decrease in expiration of methylated selenium and an increase in excretion of mercury in the bile which suggests the formation of some detoxification conjugate, and (2) a decrease in the accumulation of selenium in the livers of rats. In another instance, linseed oil reportedly offers protection against liver damage from selenium, perhaps by binding selenium in tissues in a less toxic form (61).

The body burden of plutonium, given mice by gavage or by intraperitoneal injection, was significantly greater (p less than 0.01) in iron-deficient mice than in their littermate controls. With time the translocation of plutonium from soft tissue to bone was greater in the iron-deficient mice (81).

The absorption of a trace element by plants is also influenced by the presence of other trace elements. For example, zinc and aluminum slightly inhibited beryllium absorption, whereas magnesium had no influence and dinitrophenol enhanced beryllium absorption (18).

Theoretically, synergism can occur if the mechanism of toxicity is identical for two pollutants. Thus the effects of two heavy metals might be additive if they inhibit the same enzyme system. This is especially applicable in the case of carcinogens where a "single hit" at a specific cellular site might result in carcinogenesis. Thus, the concentrations of two polynuclear aromatic hydrocarbons might be additive, and significantly increase the possibility of cancer where the concentration of either alone would not.

Other specific examples of synergistic or antagonistic effects can be found in Appendix Tables A-II-2 and A-II-3 (for inorganic compounds) and in Table IX-39 of Reference 18 for organic compounds.

Epidemiological studies are often done on urban populations to determine the effect of one or a few pollutants on such populations. In addition to exposure to chemical air pollution (such as sulfur oxides, nitrogen oxides, particulates, other elements, and hydrocarbons), urban populations are less likely to be physically active and are subjected to crowding (which can lead to general health deterioration due to greater exposure to infectious diseases) and other forms of psychological stress.

If antagonistic effects between two substances are operating in the environment, or if the psychological stress of urban living is partially influencing the epidemiological studies, methodologies such as the MEGs will tend to overestimate the possible environmental effects of specific pollutants. On the other hand, operation of synergistic effects in the environment will tend to underestimate the effect, leading to the prediction of environmentally safe concentrations which in reality would be environmentally hazardous. Obviously, there is no simple solution to this problem.

5.1.3.2.7 Cocarcinogens

Cocarcinogens are compounds which enhance the effect of carcinogens. By themselves they may not be carcinogenic but can promote multiplication of abnormal cells after initiation of the conversion of a normal cell to a malignant cell by a carcinogen. The fact that coal tar itself is more carcinogenic than known individual carcinogenic compounds, suggests the presence of cocarcinogens. In an experiment performed in 1967, Tye and Stemmer (18) removed the phenols from coal tar, and observed that the carcinogenic activity of the resulting material was significantly decreased. In 1969 Conzelman (18) discovered that the skin cancer-inducing activity of benzo(a)pyrene and of benzo(a)anthracene were increased 1000 times when n-dodecane was used as the solvent. In 1970, Laskin and coworkers (18) reported inhaling benzo(a)pyrene alone did not produce lung cancer in rats, while inhaling sulfur dioxide and benzo(a)pyrene did produce cancerous tumors (18).

The carcinogenic potential of certain PAH is greater in solvents such as n-dodecane and dodecylbenzene than in hydrocarbons of low molecular weight. Hydrocarbons which increase the rate of cancer induction by a carcinogen are capable of preconditioning the skin of mice to render it more responsive to subsequent applications of a carcinogen. The accelerating solvents are effective promoters of carcinogenesis initiated by a single application of a carcinogenic material (18).

Some additional substances which are thought to have cocarcinogenic properties are phenols, cresols, non-ionic detergents, phorbol, myristate, acetate, and anthralin (18).

The mechanisms by which cocarcinogens act are not known. Cocarcinogens have not been dealt with in the MEG approach. The cocarcinogen may make a specific cellular site more available for a carcinogen or may increase the absorption of the carcinogen by the living system. Other, more subtle effects are known; for example, methylmercury has been found to interfere with liver detoxification mechanisms, resulting in the accumulation of N-oxygenated metabolites.

5.1.3.2.8 Summary and Conclusions

Many effects have been presented which relate to the toxicity of pollutants in the environment. None of these effects readily lends itself to quantification by methodologies such as the MEG approach. Some of these effects such as bioconcentration, synergism, and cocarcinogenicity tend to increase the toxicity of the individual substances so that the level which the MEG methodology predicts to be safe for the environment may actually be hazardous. Other of these effects such as antagonistic effects and the influence of the psychological stress of urban living on epidemiological studies, can lead to predicted values that exceed those which the environment can tolerate. Other of these effects such as temperature, form of the pollutant, water hardness, and organic complexes affect toxicities in unpredictable and site-specific ways. Methodologies such as the MEGs are not, at this point, sophisticated enough to take these factors into account. Indeed, the authors of the MEGs realized this deficiency (1). However, the MEG approach is possibly the best attempt to give environmentally safe quantification, in spite of the fact that all of the factors discussed in this section were not incorporated.

It is perhaps necessary to set standards on groups of compounds rather than individual compounds. Thus, standards may read: "The maximum allowable concentration of substances capable of causing immunosuppression shall be...", "The maximum level of carcinogens and cocarcinogens shall be...", "The maximum (emission) level of substances capable of causing respiratory distress shall be...", etc. These regulations would be harder to write and enforce; but if such regulations were written and could be followed, they would probably lead to a more satisfactory end result.

5.1.4 Potential Effects of Non-Chemical Pollutants

The major non-chemical pollutants include: heat, noise, entrainment and impingement, radioactivity, microorganisms, and complex effluents (TOC, DO, BOD, etc.).

5.1.4.1 Heat and Noise

Both heat and noise will exert localized, short-range effects, generally not extending more than a few kilometers in any direction beyond the center of the plant location. Heat and noise effects may also impinge on plant workers.

As with other pollutants, the various effects will be proportional to the intensity or level of heat and/or noise, the distance between the source and the receptor, and the duration of exposure. In Chapter 3 of this report, it was stated that as much as 160×10^{12} joules of heat could be lost to the environment each day that the SRC plant is in regular operation. Considering that the White County site has excellent air dispersion characteristics, one would expect little or no downwind impacts of heat. An accurate assessment of localized heat effects can best be made, however, when the SRC demonstration plant is in full operation. Even here, site specific factors will have to be taken into account.

With respect to noise effects, the major problem appears to relate to the potential impacts on workers. Noise impacts on the White County environment can be essentially dismissed since there are no big game animals in the area. An accurate assessment of noise level contours can be made when the SRC demonstration plant is in operation. Present indications are that available noise mitigation measures would be effective in lowering ambient workplace noise levels in the high-noise areas (e.g., in the coal shaker, hydrogen generation, and boiler house units) to comply with OSHA requirements.

Thermal effects of heated water discharges into the Wabash River from the steam electric station (SES) would not likely affect the ambient thermal characteristics of the river under average flow conditions. Under the summer low-flow conditions, however, where the typical withdrawal might exceed two percent of the Wabash River flow, one would expect compliance problems with respect to rise of surface water temperatures in excess of the standard five-degree limit.

5.1.4.2 Entrainment and Impingement

The majority of auxiliary steam electric stations will use once-through cooling systems (82). Given this condition, it is apparent that the velocity of water passing through SES intake screens may be great enough to entrain and injure, or kill, small fish that pass through pumps and heat exchangers, or to kill outright the large fish striking the screens (82). Eggs and larval stages of aquatic organisms are particularly vulnerable to entrainment. The degree of impact is usually determined more by the volume of intake flow than by the intake velocity (83). Unfortunately, the ecological implications of these events are not yet known.

Key environmental factors influencing impingement or entrapment are water temperature and velocity, light intensity, fish concentration and behavioral patterns, low dissolved oxygen concentrations, the presence of toxicants, relative location and construction details of the intake structure, and the location of the intake in relation to the bottom, shoreline, and water surface.

Partial reports and predictions of the effect of entrainment events are shown in Table 5-18.

TABLE 5-18. REPORTED ENTRAINMENT INCIDENTS (83)

Power Plant	Entrainment Event	Comment
Indian Point, Hudson Estuary, N.Y.	Predicted future kill of larvae and juveniles of striped bass - 7.3 million per year.	Estimated from estuary sampling in 1966 and 1967.
Connecticut Yankee, Conn. River, Conn.	179 million fish larvae killed per year during plant operation.	Estimated in 1969 and 1970.

Reports and predictions of the effect of impingement events in power plants are shown in Table 5-19.

TABLE 5-19. REPORTED IMPINGEMENT INCIDENTS (83)

Power plant	Impingement event	Comment
Indian Point No. 2, Hudson River, N.Y.	Massive kills; maximum of 120,000 per day.	Testing of new cooling system in January 1971; white perch and other species.
Surry Power Station, James River, Va.	6 million river herring destroyed in 2 to 3 months.	Estimated by Atomic Energy Commission in October to December, 1972 during partial power runs.

According to Boreman (83), simplistic mathematical models neglect important hydrodynamic phenomena necessary for predicting flow conditions close by the power plant intakes. Dye or drogue studies are considered unreliable for prediction of the reaction of aquatic organisms to the higher velocities near the intakes (83).

If the plant discharge is located too near the plant intake area, fish and shellfish often may be subjected to entrainment and impingement. Stagnant pool areas around the intake allow the populations of aquatic organisms to increase in these areas, thereby increasing their vulnerability.

The EPA has recommended reducing maximum intake velocities to below 0.15 m per second at the trash rack to enable fish to escape the screenwell. However, the U.S. Fish and Wildlife Service considers that velocities below 0.15 m per second will entrain plankton and larvae of small fish, where intake channels are built without an effective escape bypass (83).

In the Wabash River area of White County, the fish species most likely to be impinged in large numbers is the gizzard shad; this species tends to travel in large schools throughout its life cycle. Thus, if a school approaches the intake it will experience population losses. Apparently, other fish species found in the Wabash River area will be impinged only occasionally (4).

The highest probability for entrainment of aquatic organisms in the Wabash River will occur under low-flow conditions (August to October) when fish are spawning and when planktonic populations are typically larger. Present evidence indicates that the one percent of water withdrawn for power plant use, represents the likely percentage entrainment (one percent) of ambient riverine populations. Assuming that this level of entrainment would be well within the level of natural fluctuations of riverine populations, it is likely that the losses to entrainment and impingement would have no significant effect on the biology or ecology of the Wabash River area.

5.1.4.3 Inadvertent Modification of Precipitation

Drift of the vapor plume from the cooling tower could promote fogging and icing conditions. If this drift occurs near highways, hazardous driving conditions could result.

Many studies (84,85,86) have indicated that precipitation is increased downwind of power generating facilities and other industrial complexes. Usually, this increase takes the form of increased severe storms; this may be due to a thermal effect caused by heated emissions or to an increased particulate count. Such an effect is possible in the vicinity of the hypothetical SRC facility under study. If an increased precipitation occurs on a local basis, two detrimental effects are possible. First, since most rainfall of greater than 1.25 to 2.5 cm does not increase crop yield but rather leads to erosion (87,88), the area receiving an increased rainfall will be damaged by increased erosion, hail, lightning, etc. Second, the weather modification induced by the industrial facility may lead to a depletion in the moisture content of the air due to the increased precipitation immediately downwind of the facility. This latter effect could lead to partial drought conditions farther downwind of the plant.

A statistical analysis of corn yields and weather variations in Illinois indicated that the July rainfall was the single most important weather factor, although in portions of southern and eastern Illinois, either the July or August temperature achieved higher correlations with yields. Weather factors together explained more than 80 percent of the variability in corn yields in southern Illinois, but only 45 percent of the yield variability in northern Illinois (89).

5.1.5 Natural Radioactivity

Approximately 290 millicuries (mCi) of radiation will be associated with the 28,123 Mg of Illinois No. 6 coal consumed daily by the proposed SRC facility. Is this a significant amount? In Chapter 3, treated emission streams of coal dust were shown to contain between 0.9 and 167 mg dust/m^3. This amount of dust corresponded to between 9.28×10^{-12} to 1.72×10^{-9} Ci/m^3. Of these values, from 4.77×10^{-16} to 8.85×10^{-14} Ci/m^3 is associated with the decay of each isotope of the U^{238} series; 2.2×10^{-17} to 4.1×10^{-15} Ci/m^3 with each isotope of the U^{235} series, and 2.2×10^{-16} to 4.1×10^{-14} Ci/m^3 for each isotope of the Th^{232} series. These numbers are at least three orders of magnitude below the maximum permissible concentrations listed in the Radiological Health Handbook (90) and the 10 CFR 20 Standards for protection against radiation for major radionuclides associated with coal-burning facilities.

As a second estimate, the radiological exposure of a worker breathing the dust was calculated, on the assumption that a person doing light work would breathe 28.6 l per minute or 13.728 m^3 per eight hours. If one assumes that the air breathed in contains 100 mg coal dust per cubic meter and that 50 percent of the coal dust is trapped in the lung, one finds a buildup of coal dust of 1.37 g per day; this calculates to a lung deposit of 350 g per year for a person doing light work on an eight-hour day. This assumption is the maximum possible buildup since no coal dust is assumed lost in the normal cleaning processes of the lung. Consideration of the number of disintegrations, the energy of each disintegration, and the relative biological effectiveness of each type of disintegration leads to the conclusion that a 70 kg (standard) man would be exposed to 4.47×10^{-13} rad or 3.85×10^{-12} rem of irradiation/day. Given that the worker should stay with the same job for the total plant lifetime of 30 years, and that 260 days per year were worked, the cumulative exposure would be 3.48×10^{-9} rad or 3.00×10^{-8} rem (90,91,92,93). This exposure is well below the maximum permissible rem; however, should certain western coals be utilized, the margin of safety would decrease.

5.1.6 SAM/IA Analysis of the Hypothetical SRC Facility

The quantities of materials present in the various waste streams, defined and reported in Chapter 3 of this report, have been subjected to a SAM/IA Level 2; this analysis is found in Appendix V and includes Figure A-V-8 and Tables A-V-12 and A-V-13. Generally, the results of this analysis suggest that the most significant environmental impacts are associated with the emission of carbon dioxide and carbon monoxide. Aluminum, copper, zinc, nickel, and several organic compounds appear to be present in significant amounts in the effluents. In addition, several trace elements and organic compounds appear to be present in significant amounts in the solid wastes.

The most hazardous SRC waste stream quantified to date appears to be the solid residue. Fly ash from steam generation is judged to be the second most hazardous waste stream.

Levels of aluminum and nickel in the effluent stream are judged sufficient to cause damage to field crops (1,91). Copper, at levels believed to occur in the SRC effluents, has been found toxic to many kinds of fish, crustaceans, molluscs, insects, phytoplankton and zooplankton (91,92). The high potential environmental hazard of the solid wastes indicates that considerable care should be taken to assure that these materials are disposed of in a manner that will prevent the contamination of groundwater and surface water supplies (e.g., by leaching, seepage, and overland flows).

Appendix Table A-V-13 displays a typical SAM/IA worksheet. This example demonstrates some of the problems of a SAM/IA analysis, and was based on the coal pile drainage, the composition of which was assumed to be the same as the average coal pile drainage given in Chapter 3, Table 3-14. The volume of runoff was calculated by the formula found in Chapter 3, and by assuming that all of the 102.8 cm of average annual precipitation at Carmi, Illinois, runs off a 3.24 ha coal pile. Both volumes were used and separate calculations were performed for each runoff rate. The pollutant species listed first on the worksheet (alkalinity through pH) are so general that: (1) the MATEs are not available and (2) specific environmental impacts cannot be predicted. Of the more than 250 materials for which MATEs are calculated, the analysis of only six is available for coal pile drainage. Of the 10 specific substances reported in Table 3-14 for coal pile drainage, the MATEs are available for six. No information is available which would indicate the identity and quantity of organic substances in coal pile drainage.

5.1.6.1 Other Indicators of Adverse Effects

Table 3-24 shows the changes in the concentration of a few components both upstream and downstream of a refuse pile. These data show little reason to predict any environmental impact, because the refuse pile was well covered with clay loam soil and vegetated with grass (93). Refuse piles lacking such a vegetative cover would likely cause an increase in acidity of 5,660 mg/l, in sulfate of 10,000 mg/l, in sodium of 240 mg/l, manganese of 10 mg/l, iron of 2,200 mg/l, and a decrease in the pH of leachate to a value of three. The 10 mg/l value for manganese exceeds the ambient level goals of 50 and 20 micrograms per liter, based on health and ecological effects, respectively. The MEGs for the other materials have not been determined as yet. The data presented in Table 3-24 suggest that significant environmental impacts can be expected from an uncovered, non-vegetated refuse pile. Therefore, all refuse piles should be covered with soil and revegetated as soon as practicable.

5.2 Strategies for Environmental Impact Assessment

In this portion of Chapter 5, suggestions are advanced regarding the estimation of the environmental costs (i.e., impacts) associated with the construction and operation of the hypothetical SRC plant. As stated earlier in the Introduction to this report, the somewhat arbitrary selection of a site in White County, Illinois, was considered to be a useful construct in that it challenged the analyst to separate those environmental items that are somewhat readily assessed, from those that clearly require further baseline study at a specific site. Thus, one may designate two categories of impact assessment, as follows:

- generic assessments
- site-specific assessments.

By the same reasoning, one may predict environmental protection strategies relative to the construction and operation of the proposed SRC facility, either in generic or site-specific terms. Clearly, the estimation of costs of the required environmental protection measures is highly site specific in nature; however, certain protection measures are considered generic in nature.

5.2.1 Generic Environmental Impacts

The final impact statement on the alternative fuels demonstration program (AFDP), issued in late 1977 by the U.S. Department of Energy (94), provided generic assessments of the impacts of the emerging synthetic fuels technologies on a regional basis. The AFDP report assessed the generic impacts of coal gasification and coal liquefaction plants of various sizes and composition, including that of the required auxiliary or conjunctive developments for several coal-producing regions, among them being the Eastern Interior Coal region (Illinois, Indiana, and Kentucky). The reader is advised to consult this AFDP report for details on the Eastern Interior region. Suffice to say that environmental impacts were assessed in terms of the physical, biological, and socioeconomic environments. Significant uncertainties identified in the AFDP report included: qualitative emission of toxic substances; minimum in-plant water use requirements, basis for predicting ecological and health effects of coal liquefaction plants, and the efficiency of pollution control devices. Therefore, additional research will be needed to resolve these and other uncertainties related to the development of synthetic fuels.

5.2.2 Site-Specific Impacts

As pointed out by Ramsay (95), site-specific parameters and plant technology items are determinate to both the environmental and the economic costs. Inspired by the approaches currently in use by the Nuclear Regulatory Commission in early site reviews, and by the State of Maryland and some utilities in their acquisition of alternative power plant sites (so as to ensure backup sites for future energy needs) Ramsay (95) advanced certain methods for expressing environmental impacts on a dollar basis. The rationale underlying this approach was that it would be rather artificial to insist on not expressing environmental costs in dollars, and that this approach prevents one from hiding certain value choices.

The most readily discernible site-specific environmental impacts in the White County area include the following:

- Land area consigned to the mining of coal and to plant site (including cooling ponds, coal storage area, and tank farm) for the 20- to 30-year lifetime of the plant (see Table 5-20)

- Land area consigned to borrow pits and waste disposal sites (based on geological criteria)

TABLE 5-20. ESTIMATED LAND AREA CONSIGNED TO THE SRC COMPLEX (97)

Facility unit	Land area (ha)
Coal mine (surface)	
Total mine area	15,540.3
Active area of surface mining	2,331.0
Additional mine area for large surface mines	31,080.6
Landfill at mine	777.0
Mine support buildings	259.0
Coal preparation plant	85.47
SRC plant area (including waste pond and other areas)	259.0
Buffer zone area surrounding plant	777.0

- Changes in lifestyles
- Stresses imposed on the infrastructure of state and local governments in accommodating the synthetic fuels technology
- Earthquake (seismic) risks
- Meteorological criteria
- Population-center distance limits
- Hydrologic considerations (e.g., flood hazard and water quality)

- Ecosystems, (i.e., location of vulnerable ecosystems) aquatic and terrestrial

- Alterations of existing land use.

The goal of the Ramsay (95) analysis is to identify relative siting feasibility for different geographical grid points (on a 3.6 hectare scale) for each reasonable permutation of a set of specific design technologies, whereupon the environmental costs are determined. These environmental impacts and costs are then estimated in terms of the following categories: geology, seismology, meteorology, population centers, hydrology, ecosystems, land use, transportation, and transmission lines, as shown in Appendix Table A-V-14.

5.2.2.1 Land Area

Estimates of land area consigned to the SRC complex, including coal mine, plant site, auxiliary site, roads, railroads, and landfill site are given in Table 5-20. In essence, the land area consigned to the mine site would generally impact counties other than White County, since there are no operational mines in White County at the present. However, Lindquist (96) has reported that mineable coal reserves do exist in White County. Assuming that the coal would be surface mined in adjacent counties, it appears that a total of 1,036 ha (2,560 acres) would be required for the SRC plant and auxiliary units. Should a new reservoir be required, an additional 518 ha would be utilized (97).

5.2.2.2 Geology

The U.S. Soil Conservation Service and most state geological surveys provide various criteria for large-scale site screening and impact assessments. One of these is the slope from which estimates can be made of the amount of soil and rock materials to be moved. Some states require that routine estimates of the area and volume of cuts and fills shall be included in the erosion and sediment control plan as a contingency to the granting of a construction permit. Included with the latter is an estimate of the location and extent of borrow pit areas. As a matter of fact, the regulatory process incurs many costs, referred to as transaction costs (95). These include the costs of hearings and public meetings, costs of time losses resulting from unresolved issues of various kinds, and costs incurred for environmental monitoring and baseline surveys at specific sites (95). Other aspects of the geology category are shown in Appendix Table A-V-14.

5.2.2.3 Potential Changes in Lifestyles

Beyond question is the fact that a synthetic fuels technology would sharply change the lifestyle of White County from a rural to an urbanizing mode. Compared with the northern Great Plains area, the trauma of lifestyle changes in the southern Illinois area would be nominal.

5.2.2.4 Potential Stress Imposed on State and Local Infrastructure

The state government of Illinois appears admirably suited to coping with the demands on water, roads, open space, flood-prone areas, and the like. Local government, as in White County, although admirably supported by long-range planning inputs from the Greater Wabash Regional Commission, may suffer from the lack of good zoning regulations. Somewhat compensatory controls on land use, however, are implicit in the Federal Clean Water and Clean Air Acts.

5.2.2.5 Seismology

Extra construction costs required to cope with earthquake hazards were discussed in Chapter 4. The apparent risks to the safety of synthetic fuels workers resulting from potential rupture of conveyor systems and reactors have not been assessed.

5.2.2.6 Meteorological Criteria

Because of the likelihood of recurring tornadoes in southern Illinois, it is apparent that construction design criteria should be factored in. Considering that the seismic design criteria would be more than adequate to resist tornadoes, however, no further action need be taken in this regard.

With reference to compliance with the six criteria air pollutants, the situation will require that site-specific estimates of compliance be made for each possible design technology (e.g., dust collectors and scrubbers) at given geographical points for a specific plant. Based on the Ramsay (95) framework of analysis, the cost for meeting the air quality criteria standards would be zero, and infinite for not meeting the standards.

5.2.2.7 Hydrology

The problems of flooding along the Wabash Basin were discussed in Chapter 4. Other assessments include the cost of pumping and piping water from the Wabash River for a distance of several kilometers to the SRC facility. Obvious tradeoffs that should be assessed refer to the comparative costs of locating the facility close to the Wabash River, versus piping water over a distance of several kilometers.

Various aspects of the analysis of hydrology are shown in Appendix Table A-V-14.

5.2.2.8 Aquatic Ecosystems

In the nuclear power plant field, a criterion for assessing the environmental cost of entrainment and impingement of fish and other aquatic organisms has been based on the percentage of water taken from the stream. An acceptable range in percentage water removal was suggested to be from 10 to 20 percent (95). Should the removal of water equal the 20 percent upper limit, the installation of a cooling tower instead of a once-through cooling system would qualify as a partial abatement solution. At a water removal of 30 percent, the costs of entrainment and impingement would become infinite (95). For the most part, however, aquatic habitat impacts must be treated on the basis of a detailed site analysis. In rough estimates for site screening purposes, Ramsay (95) suggested using only the gross water areas impacted by water-use type as the basis for estimating impacts on aquatic ecosystems.

5.2.2.9 Land Use

The most direct quantitative measure of the impact on prime farmland of the SRC facility and conjunctive developments is the number of acres consigned to the overall activity, as shown in Table 5-20. According to Ramsay (95), an unacceptable impact on prime farmland would occur when 10 percent of the state's cropland area, and/or five percent of the national cropland area were utilized for the siting of power plants.

5.3 Strategies for Environmental Protection

Elsewhere in this report (see Chapter 4) a general discussion of environmental monitoring was presented. In this segment of the report, an effort will be made to place environmental monitoring activities into overall perspective relative to the proposed SRC facility. For example, monitoring comprises the following functional sequence: problem recognition, monitoring, evaluation of data, and formulation of policy options (98). Figure 5-9 provides a somewhat idealized scheme designed to protect human health from direct threats. The functional sequence iterated above contains many feedbacks between phases. For example, a monitoring system may generate data leading to the establishment of legal emission standards. In due course, the monitoring system may be modified to insure that the standards are having the desired effect and that compliance is being achieved (98).

The U.S. Department of Energy's final impact statement on an alternative fuels demonstration program (AFDP) cited the following strategies for environmental protection, commencing with siting considerations and going through the full operational phases, as follows (94):

- Selection of sites for specific synthetic fuels projects
- Application of mitigation measures against construction and operation activities comprising the synthetic fuels program (see Chapter VIII, Volume I, of AFDP Report)

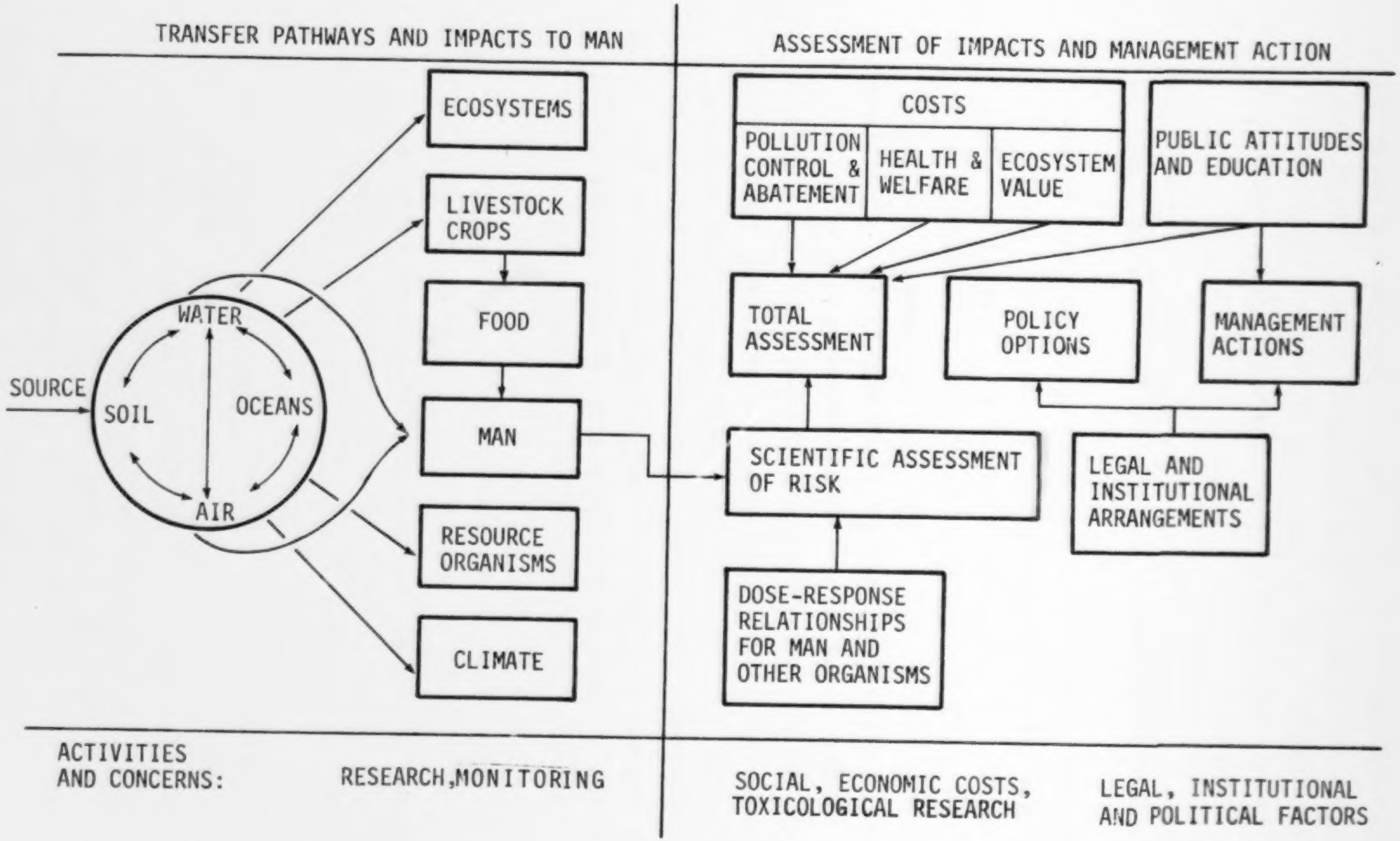
TRANSFER PATHWAYS AND IMPACTS TO MAN
ASSESSMENT OF IMPACTS AND MANAGEMENT ACTION
SOURCE
SOIL
WATER
OCEANS
AIR
ECOSYSTEMS
LIVESTOCK CROPS
FOOD
MAN
RESOURCE ORGANISMS
CLIMATE
COSTS
POLLUTION CONTROL & ABATEMENT
HEALTH & WELFARE
ECOSYSTEM VALUE
PUBLIC ATTITUDES AND EDUCATION
TOTAL ASSESSMENT
POLICY OPTIONS
MANAGEMENT ACTIONS
SCIENTIFIC ASSESSMENT OF RISK
LEGAL AND INSTITUTIONAL ARRANGEMENTS
DOSE-RESPONSE RELATIONSHIPS FOR MAN AND OTHER ORGANISMS
ACTIVITIES AND CONCERNS:
RESEARCH,MONITORING
SOCIAL, ECONOMIC COSTS, TOXICOLOGICAL RESEARCH
LEGAL, INSTITUTIONAL AND POLITICAL FACTORS

Figure 5-9. An idealized management system for protecting human health (98)

- Development of a comprehensive monitoring program to obtain data on environmental impacts resulting from synfuels projects, and to ensure compliance with all applicable environmental requirements and standards.

5.3.1 Generic Strategies for Environmental Protection

The DOE/AFDP report (94) provides good generic treatment of measures to mitigate potential impacts of coal-based development (see Chapter VIII of AFDP report). However, the problem of "false security" arises because past experience says that the plan will not be closely followed, and therefore results will be far from excellent. Questions can also be raised relative to whether compliance with applicable standards is sufficient. Known pollutants should be controlled even though standards have not been set. Two objectives of the AFDP environmental protection strategy are: the development of a complete environmental knowledge base for any subsequent synfuels commercialization to include technical, environmental, and socioeconomic data; and the selection of specific synfuels projects that are environmentally sound in design, construction, and operation. (See Chapter I-C of the AFDP report for details.)

The prevention of adverse impacts resulting from the construction and operation of the proposed SRC facility will include the following steps (94):

(1) A carefully prepared development plan for individual synthetic fuels plants, mines, and related facilities will be required. This plan will specify environmental protection tactics which will be utilized for that specific facility. Government approval of the site development plan

and major changes thereto will be needed before beginning construction.

(2) The development plan will be coordinated with the land use, transportation, and other plans of local and state agencies.

(3) The development plan will identify the applicable federal, state and local environmental standards and guidelines that must be complied with by each facility.

(4) The development plan will identify the environmental control technology to be used for each facility. The best available technology would be required in all cases.

(5) A comprehensive environmental monitoring and surveillance program will be undertaken. All environmental standards and contractual provisions will be rigorously enforced. Physical facilities and records will be open to government inspection.

(6) Procedures for state and local inputs into specific project decisions will be developed.

(7) Various mechanisms will be considered to promote environmental protection. Security bonds can be posted to guarantee sound development and restoration. The incentives program can provide for reimbursement by the government of extraordinary environmental control cost or cost due to unanticipated environmental delays. The government can ensure that funds for reclamation will be available in the event of plant failure.

(8) Early warning mechanisms will be used to make certain that potential environmental threats will be promptly identified and corrected (94).

5.3.2 Site-Specific Environmental Protection Strategies

The U.S. DOE/AFDP report (94) states that environmental data will be collected at each synfuels site before beginning construction; this will provide an accurate baseline for assessing significant changes in air, water, and land values should the SRC plant be built and operated at that site.

With reference to the proposed White County site, as well as other sites, it is apparent that site-related baseline information will be needed in order to develop the best environmental protection strategies for the following substances (94):

- All regulated substances, such as those under NAAQS (see Chapter 2 of this report), Public Health Service Drinking Water, and all other environmental and occupational (OSHA) standards promulgated by federal and state authorities
- All unregulated and suspected carcinogens, mutagens, and teratogens
- All other substances and factors of concern.

With reference to those environmental attributes peculiar to the White County site, and for which detailed baseline, site-specific information will be required, the following are considered to be of major importance:

- Assessment of groundwater contamination resulting from overland flows and seepage from the plant area and from waste disposal areas

- Downwind effects of the cooling tower plume and of stack emissions on high-dollar-value field crops and natural preservation areas

- Detailed evaluation of the subsurface soil permeabilities to liquids and gases

- Effect of CO_2 and CO emissions on the inadvertent modification of local precipitation patterns

- Rates of dispersion and dilution of key SRC effluent pollutants in surface waters of White County, Illinois

- Rates of dispersion and dilution of key SRC emissions in the local atmosphere of White County, Illinois.

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6.0 POLLUTANTS OF CONCERN AND SUGGESTIONS FOR APPROPRIATE GOALS

In Chapter 3 of this report, an attempt has been made to quantify the pollutants which will be discharged to the environment as a result of the operation of the SRC-II facility. In Chapter 5 the hazards of the major pollutants emanating from the SRC plant are described along with an estimation of their impact on the environment, with emphasis on the White County ecosystem. In this chapter, suggested environmentally safe goals, based on the MEG rationale for coal conversion technologies, will be examined.

Suggesting goals for pollutant discharge levels is complicated by the complexity of the system and imprecise or incomplete scientific knowledge. Four major sources of difficulty in the setting of meaningful environmental goals include: the transport of pollutants through the media of air, water, and land; the transformation of compounds from harmless chemicals to damaging pollutants in the environment by physical, chemical, or biological means; the synergies through which two or more substances or agents interact to create a significantly more damaging effect; and the difficulty of establishing a threshold for effects when even low-level doses are suspect. The production of photochemical oxidants and the transport of air pollutants from region to region are examples of phenomena that must be better understood (1).

Synergistic and antagonistic effects are especially difficult to predict. For example, the mutual antagonism of mercury and selenium toxicity is probably due to the interaction of these two elements to form an inorganic or organometallic complex, but the existence of such a complex in biological systems is difficult to predict from the inorganic chemistry of the individual elements.

Complexities in the prediction of the effects of complex waste and product streams on the environment were discussed in Chapter 5 of this report (see Appendix Tables A-II-2 and A-II-3 for examples of synergistic and antagonistic effects). However, all possible examples of synergistic and antagonistic effects will, by definition, never be tested.

The report entitled "Multimedia Environmental Goals for Environmental Assessment" (MEG) (2) utilizes a methodology in which laboratory and environmental data are subjected to well-defined mathematical manipulations. The resulting numbers are used to indicate pollutant levels which may be safe for the environment. The MEG report is discussed at length in Appendix I of this report. The mathematical manipulations are based on logical considerations given in the MEG report. These manipulations give rise to two sets of values for air-, water-, and land-destined wastes. Each set has one value based on health effects and one value based on ecological effects. The first set of values is the minimum acute toxicity effluent (MATE) and reflects the concentration that the mathematical treatment predicts would not harm the environment, if present in the effluent stream. The second set is the ambient level goal (based on the estimated permissible concentration) which is an indication of the concentration in the air, water, or soil which the mathematical treatment predicts will not harm the environment. It is possible that both these numbers will be derived from the same experimental data. For compounds that have a current standard, the ambient level goal will be one-fifth of the MATE. Generally the ratio will be 420. Since the MATE is the level in the effluent stream which will not cause environmental damage, and the ambient level goal is the concentration in the receiving stream which will not cause environmental damage, this relationship assumes a dilution factor of five (or 420) in all cases. Because the dilution factor will be site specific, one deficiency of such a generalized approach becomes obvious.

The MEGs represent objective "best guesses" at levels that will not cause damage if released into the environment. For example, when the MATE is much larger than the ambient level goal, the environmentally safe standard should be based on the ambient level goal. Such a standard might be five times the ambient level goal. Alternatively, such a standard might read "...such that the level in the receiving media (air, water, or land) shall not exceed (the ambient level goal)." This latter method circumvents the problem of receiving media dilution factors affecting the MATEs and the ambient level goals in an unpredictable site-specific manner, but it might be harder to enforce. The MEGs are not designed to take into account all the possible complex interactions between compounds. Cocarcinogens, by definition, potentiate the effects of carcinogens. Perhaps an upper limit should be set on the "concentration of carcinogens" and on the "concentration of heavy metals binding with sulfhydryl groups," or on the "concentration of carcinogens and cocarcinogens," and so on.

The MEGs are based on mathematical manipulations of the data uncovered in an exhaustive literature search. As such, the most current MEGs, particularly the MATE, should receive primary consideration in setting guidelines. The MATEs and ambient level goals are listed in Appendix VI. Also given is some current information on the individual MEGs which should, and undoubtedly will, be considered as the MEGs are updated.

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7.0 RESEARCH NEEDS

7.1 The SRC Technology

The discussion in Chapter 3 relative to estimated pollutant discharge levels from the hypothetical SRC facility revealed a number of processes that may require further study; these are summarized below without any attempt at ranking.

- Leachability of all slags generated by the gasifier and other modules
- Ambient and chemical composition of solid and hazardous wastes generated by the SRC-II technology
- Concentrations of trace elements and acidity emanating from nonvegetated refuse piles compared to vegetated refuse piles
- Amount of sediment, chemical wastes, and non-chemical wastes generated during the construction of the SRC plant
- Concentration and distribution in particulates of natural radionuclides, trace elements, and organics in or sorbed by particulate-size classes
- Comparison of the effectiveness of standard versus improved dust control measures in coal preparation, storage, and receiving areas

- Localized (downwind) environmental and vegetational effects of cooling tower plume drift in different parts of the United States

- Amount and chemical composition of catalyst dust and carbon monoxide emissions

- Cost effectiveness and feasibility of using ion exchange, reverse osmosis, and other techniques to treat cooling tower blowdown water

- Requirements for chemical stabilization of dewatered sludges

- Increased costs for building construction plant equipment to withstand possible earthquake damage

- Chemical interactions occurring among components of raw water treatment sludge

- The effect of process operating variables on the composition and volume of SRC-I and SRC-II products and by-products

- The effectiveness of various wastewater treatment methods in the removal of polynuclear aromatic hydrocarbons, polycyclic N-aromatics, and polycyclic hydroxy compounds.

7.2 Environmental Assessment and Monitoring

Based on the discussions in previous sections of this report, further research in the following aspects of environmental assessment and monitoring will be required to more fully assess the impacts of the SRC technology:

- Better information on both discharged pollutants and their environmental effects

- Ambient pollutant levels (i.e., background levels) without the presence of an operating SRC plant

- Standardized sampling and analysis methodologies as a means of improving the cost effectiveness of environmental monitoring programs

- Epidemiological methodologies capable of predicting the effects of changes in pollutant level on normal versus high-risk populations, sensitive versus nonsensitive subpopulations, etc.

- Public health impacts from a given level of atmospheric emissions within and between different geographical locations or regions

- Effects methodologies suitable for establishment of regulatory policy for synfuels technology.

Individual SRC pollutants that require site-specific study include the following:

7.2.1 SRC Pollutants Requiring Site-Specific Study

7.2.1.1 Emissions

- Carbon dioxide
- Carbon monoxide
- Coal dust
- Catalyst dust.

7.2.1.2 Effluents

- Aluminum
- Copper
- Nickel
- Zinc.

7.3.1.3 Solid Wastes

- Gasifier slag
- Fly ash
- Sludges.

These needs are consistent, in general terms, with the findings of the EPA-sponsored Study Group on Monitoring (1). For example, one of the more important recommendations made by that group was that new monitoring programs should be preceded by prototype studies. The Study Group emphasized that such prototype studies should ideally include an analysis of cost versus benefits. Failing this, an analysis of the cost effectiveness of the environmental assessment and monitoring programs should be made. Careful planning is required well ahead of the implementation of monitoring programs. For example, a good understanding of environmental processes is a prerequisite to most prediction problems (1).

In terms of dollar costs, about 90 percent of the current air and water quality monitoring in the United States is reportedly performed by state, local, and private groups (1). Apparently, the assignment of responsibilities for environmental monitoring is fragmented and short-ranged; does not adequately serve the needs for evaluating longer-term changes in environmental quality resulting from industrial activity; and generally falls short of the need to determine interrelationships among sources of pollution, ambient environmental quality, and effects on humans, animals, and plants. More detailed information on the broad objectives to guide the design of source, ambient, and health effects monitoring is reported elsewhere (1).

In Chapter 4 of this report it was stated that no federal programs presently exist that require an industry to monitor the several process waste streams. Beyond this, there are no programs that require an industry to assess the environmental effects of the potentially hazardous wastes that it generates, although some leading industries do so on a voluntary basis. In view of these perceived limitations, the National Research Council (1) has recommended that before a new technology is set up, the substances that will be discharged should be identified and their potential environmental effects assessed. Some progress is already being made in this regard.

One interesting prototype study of note is the METER program started in 1976 by the U.S. Department of Energy. This program will attempt to establish whether the heat and moisture released from four different operating power plant cooling facilities (cooling towers and ponds) can affect local precipitation patterns within a 10-mile radius of the facility (2).

7.2.2 Epidemiologic Methodologies

One compelling reason for the construction and operation of a demonstration coal liquefaction plant is that it would provide the best source of prototype site-specific information from which to construct and test computer models and to conduct epidemiologic surveillance. The wedding of computer technology with epidemiology could relieve the known drawbacks of the latter. For example, when a mixture of pollutants is being studied, the computer could be used to separate the effects of the individual pollutants. The use of a computer to evaluate the final effect of a pollutant known to be present in a waste stream appears to be a more attractive alternative than that of using the same computer to determine the transport of the pollutant and the concentration likely to be found in the exposed organisms, especially since much of the information needed by the computer for this latter task is difficult to determine and consequently unavailable. Information on the concentration of a pollutant in the organism may be of little value in predicting the final effect(s). Synergistic and antagonistic effects should become apparent when a computer is used to evaluate epidemiological effects. These epidemiological surveillance studies should last at least five years and should:

- Involve more than one area with similar study populations and measurement of health indicators

- Employ a standard reliable method of monitoring ambient pollutant concentrations

- Comprehensively identify point sources of pollutant release into the atmosphere

- Record the proximity of human populations and their high-risk individuals to those point sources

- Where symptomatology attributed to the pollutant(s) is observed, monitor the environment for pollutant concentrations at increasing radial distances from the point source(s) until an area is reached where citizen complaints are not evident

- Monitor health effects while short-term elevations in ambient air pollution are actually occurring, rather than determining the effects after the fact

- Monitor survey populations containing a substantial number of high-risk subjects and, if applicable, monitor people occupationally exposed within the source of pollution

- Employ a wide variety of thorough techniques (regular telephone contacts, adequate medical examinations, questionnaires, health diaries, vital statistics, etc.) to obtain information on the health effects of the pollutant with careful consideration of subjective symptoms

- Publicly encourage citizens to report to local health agencies unusual symptoms from suspected pollutant exposures in an effort to obtain information beyond the selected survey populations (in both exposed and unexposed populations)

- Attempt to investigate the possible synergistic health effects of each pollutant with other pollutants (3).

7.2.3 Ambient Monitoring of Pollutants

Ambient levels of pollutants change with time and establish trends or variable environmental quality. The measurement of trends requires a base from which to measure changes (1). At present, too few monitoring programs exist that will provide a base from which to measure changes in levels or effects of residuals. The creation of such a base would reveal the pollution contribution from natural sources and natural transport, such as stormwater overland flows, airborne dust, and cosmic and natural radiations (1).

The two methods of establishing base trends are as follows:

- Monitoring in an area with hydrologic, meteorologic, and other characteristics similar to the area being studied, but possessing only minor anthropogenic pollutant sources
- Monitoring in a consistent manner in a given area before and after new sources of environmental degradation occur or new control programs are established (1).

These two approaches may be combined in order to establish a comparison series.

The ambient levels without pollution need to be established for the individual elements and inorganic and organic compounds. Obviously, a waste stream concentration equal to the ambient level before "pollution" will have no effect due to that particular substance. A waste stream containing either higher or lower pollutant levels than that of the receiving medium may have an adverse effect. A concentration of an essential substance in the waste stream lower than the ambient level could cause deficiencies of this material because the waste stream carrier (air or water) might dilute the material below that which would be required by the ecosystem. In this context, the components of the waste stream which are essential to the ecosystem should be defined as carefully as possible. Obviously, the very complex nature of the ecosystem precludes complete definition of all the components essential to the ecosystem.

7.2.4 Sensitive Subpopulations

In general, sensitive subpopulations include: infants; children; the elderly; the sick, especially those with chronic diseases; and those whose diet and/or geographical location subjects them to higher ambient levels. The season of the year and general activity level of the organism also influences the toxicity. However, little is known about the specific subpopulations susceptible to specific pollutants.

Human subpopulations which may be more sensitive to each individual pollutant should be identified. For example, subpopulations which are thought to be more sensitive to the effects of manganese include psychiatric patients, pregnant women, and those suffering from emphysema, chronic bronchitis, iron-deficiency anemia, and liver disease (4). People who eat fish (especially tuna) are more subject to mercury toxicity since fish tend to concentrate mercury. Cigarette smoking is known to add 0.01 to 0.08 micrograms of cadmium per cigarette to the total body burden; cigarette smoking may add other heavy metals to the total body burden. People living in areas where ambient levels of pollutants are naturally high in food and water may be either more subject to the pollution effects because of the increased exposure, or less subject to toxic effects because the low level of contamination could induce detoxification mechanisms in the exposed populations. People with certain enzyme deficiencies may be more susceptible to the effects of pollution, especially if the pollutant inhibits the deficient enzyme or inhibits an alternate pathway which compensates for the enzyme deficiency.

As an example of a more sensitive subpopulation, a level of 40 μg lead/100 ml of whole blood in children is considered to be the level above which toxicity and undue body burden occurs. However, for a child with anemia, the clinical effect of 40 μg/100 ml may well be equivalent to that at a higher blood level in a child with normal blood. The observed summer increase of lead levels in children suggests that a child with blood concentrations on the borderline in winter may well get worse with seasonal change. Children who become acutely ill may mobilize large amounts of lead from bones into the blood stream, with a resulting sharp rise in blood lead concentrations (5).

7.2.5 Further Literature Searches

Further literature searches need to be performed. The authors of the MEGs (6) reported numerous information gaps. These gaps result from either (1) the nonexistence of the required data; or (2) its existence in other than the readily available literature. The MEGs make the most use of readily available data, hence in-depth searches into the journals of chemistry and toxicology were not performed. This remains to be done and will very likely yield data to allow numerous gaps in the MEG charts to be filled. In-depth literature research relative to synergisms, antagonisms, specific compound associations, epidemiological studies, and results of bioassay studies of complex effluents should be conducted simultaneously. Also, nonchemical degradants such as heat, noise, land usage, water usage, subsidence, and visual effects should be investigated. Models should then be developed to incorporate these data into the MEG methodology to further improve the reliability of the system.

Some knowledge is available on excretion patterns of heavy metals, but little is known of that mechanism. Perhaps more knowledge is available, but this may be buried in the literature. Scientists should take more time to compile and critically review this knowledge (7).

Literature searchers should emphasize the questions asked in this section, since these questions may have already been answered and reported in other than the readily available literature.

7.2.6 Methodological Needs for Regulatory Policy Development

The several questions which require answering in order for a realistic regulatory policy to be espoused include the following:

- How should plant type, size, complexity, and product mix enter the regulatory picture?
- Can policy be structured to reward process improvements that reduce environmental impact?
- Should limits on the discharge of a pollutant be established for individual unit operation or for larger systems, including the total plant?
- How can regulatory policy accommodate tradeoffs among different process operations?
- To what extent is it possible to implement a multimedia (air, land, water) approach to environmental control that minimizes overall environmental impacts?
- How does one evaluate cross-media tradeoffs?

The three principal elements for this evaluation involve (1) characterizing the rates and types of emissions to air, water, and land as a function of the coal-feed type and the characteristics of process and environmental control technologies; (2) examining how these emissions are transferred through various media (air, land, or water) to receptors in the environment (humans, plants, and animal life); and (3) evaluating the damage incurred by these receptors from exposure to the various pollutants. This type of methodology would yield a benefit/risk/cost analysis of alternative regulatory standards. An idealized framework relating to the protection of human health through environmental management strategies is shown in Figure 5-9.

7.3 Environmental Sciences

Research needs in the sciences comprise a continuum of effort that bridges the several areas discussed under environmental monitoring. For example, data collection alone will not serve fully to resolve the several prediction problems confronting an emerging synfuels technology: an understanding of environmental processes and the mechanisms of action of pollutants is also required (1). Certain key items that will require further study with reference to an emerging synfuels technology are as follows:

- Various facets of synergism and antagonism in the environment
- Chronic effects of different forms of pollutants
- Possible effects of the degradation products of substances in waste streams

- Clinical screening tests directed to the early detection of subclinical manifestations, particularly among workers

- Mechanisms of pollutant absorption, transport, and overall action

- Body burdens causing adverse health effects

- Intermedia exchange

- Excretion kinetics.

7.3.1 Synergism and Antagonism

The various facets of synergism and antagonism need to be studied and the information disseminated. For example, proper nutrition education programs for workers exposed to high levels of manganese should be initiated, since dietary deficiency of iron is known to cause excessive retention of manganese. Additional kinetic studies should be conducted to describe reactions between manganese and sulfur dioxide, which produce sulfuric acid and/or sulfates in the atmospheric environment (4).

Zinc concentration of serum decreases after stress or after the administration of glucose (7). Can this be generalized to other heavy metals and is this good or bad? Where does the zinc go? Once in the body, nonessential metal ions may influence the content, the concentration, and the normal distribution of other metals in various tissues and fluids. This aspect of the biological metal problem is not well understood. Little has been done on the actual displacements by exogenous toxic metal of the normal complement of metals in an organ or tissue. We know little of metal shifts. Perhaps the majority of studies have examined cadmium as a toxic metal and its interrelationships with a variety of metals like copper, iron, and especially zinc (7).

In some cases zinc can antagonize the toxic manifestations of cadmium; in a few, but not all, cases, zinc can also negate the carcinogenic effect of cadmium. The mechanism by which zinc antagonizes the cadmium reaction is not really known, although speculation has occurred. For example, these two elements are in the same column in the periodic chart and have the same outer-shell electronic configurations. Zinc is essential; cadmium is not. Therefore the first approximation can be that zinc in large amounts displaces cadmium. On the other hand, cadmium is associated with alpha-globulins, whereas zinc is associated with both alpha- and beta- globulins. Blood cells pick up zinc more avidly than cadmium; the liver, the kidneys, and the pancreas take up cadmium, whereas only the pancreas takes up zinc. Cadmium undergoes different metabolic pathways in the rat than does zinc. One can speculate on how zinc antagonizes cadmium toxicity; in all probability it is not simple-ion antagonism, for there are marked biological differences (e.g., in ion turnover). Zinc may protect against cadmium toxicity by an indirect mechanism; i.e., zinc may stimulate the induction of metallothioneine and thus increase the amount of this special protein that can scavenge the cadmium (7).

7.3.2 Chronic Effects

The effects of different forms of pollutants on aquatic and terrestrial ecosystems, especially the chronic effects, need better definition. For example, available evidence indicates that long-term exposure to low concentrations of lead and mercury may lead to psychological disturbances and deleterious effects to the central nervous system. Studies need to be done to determine possible genetic and congenital effects. Experiments on animals should be performed to determine maternal-fetal effects including possible genetic abnormalities, chromosomal aberrations, and teratogenic effects in relation to long- and short-term exposure at various levels. Follow-up studies should be conducted to observe neurological damage or behavioral dysfunction. Pathological findings should be carefully correlated with exposure doses and tissue levels of pollutant. The possible consequence of the transmission of pollutants through human milk should be investigated. Behavioral studies should be conducted on children up to five years old who have been exposed to prolonged low levels of lead and mercury as infants.

There is evidence that cadmium stored in the body may accumulate over a period of thirty or forty years, that this buildup may be associated with shortened life span, and that the death rate from heart disease in cities with elevated atmospheric concentrations of cadmium may be higher than in locales where the concentration is low (5).

Determination of the chronic effects of individual pollutants through the use of epidemiological studies is complicated by the possible interactions between pollutants and by the possibility that the observed effects may be due to other pollutants. Also, the harmful effects of the individual pollutant may be increased by the presence of other pollutants.

The damage to human health depends not only on the dosage level of pollutants, but also on the physical condition of each individual. There is virtually no single threshold of pollutant concentration below which health damages will not occur. At every level of a pollutant concentration, someone could be adversely affected. In view of the wide range of physical conditions of humans, the threshold of pollutants may be viewed as a symmetrical distribution. The "mean" level of this distribution is usually used to calculate the damages resulting from pollution (8).

The authors of the MEGs reported that for situations in which contaminant levels in workrooms have resulted in increased cancer incidence in workers, it is often impossible to determine the effective dosage. Thus an adjusted ordering number cannot be calculated. A mechanism for including such data into the MEGs needs to be developed. Another problem also arises with respect to the tests performed to determine carcinogenicity. In a number of cases, tests were carried out with a mixture of substances and thus cannot be interpreted as evidence of carcinogenic potential for a single compound (6).

7.3.3 Degradation Products

The possible effects of products of the substances in waste streams should be evaluated. These effects include innocuous substances being changed to toxic substances by environmental interactions. These environmental interactions could include metabolism or photochemical reactions.

7.3.4 Subclinical Effects

The subclinical effects of pollutants should be investigated so that the places where pollution should be discontinued could be defined before clinical effects are manifested. The public should be encouraged to watch for such effects. Clinical screening tests should be conducted in which comprehensive physical and psychological examinations and laboratory procedures are performed with particular attention to the early detection of clinical and subclinical reactions (5).

7.3.5 Mechanisms of Action

The mechanism of action of the various pollutants should be understood. This is especially important if regulations regarding the concentration of "total carcinogens" or "total substances capable of reacting with protein sulfhydryl groups," as suggested in Chapter 6 of this report, are to be developed. Obviously, if the "single hit" theory for carcinogenesis is correct and two or more substances are capable of interacting with the specific cellular site responsible for carcinogenesis, the total concentration of these substances should be regulated rather than the concentration of the individual substances. This is also true for other pollutants which affect other specific cellular sites. The susceptibility of specific cellular sites to chronic exposure must also be determined.

Little is known about how metals affect the immune system of animals. Contaminant metals seem the most logical candidates for study. For example, lead suppressed the immune response in mice; nickel and chromium inhibited the antibody response of rats to immunization with a bacterial virus. The time of administration of cadmium determined the enhancement or suppression of antibody synthesis in rats (7).

The mutagenicity of metals in bacterial or mammalian species is also poorly understood. The scarcity of literature on this subject is striking. Manganous chloride was noted to be a bacterial mutagenic agent in 1951, and similar results were noted in 1965 in bacteriophage. Chromium has also been investigated in bacterial systems, but very little research seems to have been done in mammalian systems (7).

The reactions of metal ions with nucleic acids and their constituent bases are well known. It is now possible to predict that some metals will combine with the phosphate moiety and others with the basic nitrogens of the bases. For example, nickel was found to form a salt with guanosine 5'-monophosphate but not via a phosphate bond. We know so much about this phase, but we know so little about the function of these metals in nucleic acids (7).

Eventually we will have to know more about metal shifts in cells. Does cadmium displace zinc, copper, manganese? If so, what effect does this shift have on the metalloenzymes dependent on the essential metals? Is the thermodynamic stability such that shifts do not take place? Also, we will have to determine the preferred oxidation states of these heavy metals as they are transferred in the body. If Mn_xO_y is inhaled, is manganese reduced to an oxidation state of 2, or is it oxidized to an oxidation state of 4? The oxidation state may be related in some way to toxicity. Questions can also be raised about nickelous and nickelic ions (7).

The mechanism of absorption in the lung is open to question. For example, how are sparingly soluble compounds solubilized? Certainly, as foreign bodies they may be subjected to phagocytosis. Does this aid in dissolution? Is there a biological solubility table; that is, are chlorides more soluble than oxides, which are more soluble than sulfides? No available data have been found to answer these questions (7).

Some information is available on the solubility of metallic powders in the rat after the material has been injected deep into the muscle. The rate of solution is much greater than would be predicted from physical-chemical data alone. To dissolve, a metal must be oxidized, but we do not know the mechanism (7).

How much exposure is expected by direct ingestion of contaminated soil by animals? In what form is the pollutant in these soils? How effectively can the pollutant in this form be removed from the soil and/or absorbed from the gastrointestinal tract? How much of the pollutant can be inhaled in dust? Is the form of the pollutant different in the soil than in the vegetation grown in this soil? How does this difference in the pollutant form affect its absorption by the gastrointestinal tract? How do soil microorganisms alter the form of the pollutant? Does this change make absorption of the pollutant by the plant easier or more difficult? Are there other physical or chemical phenomena (such as photochemical changes) which would affect the form of the pollutant in the soil and its subsequent absorption? We need the answers to all of these questions (7).

7.3.6 Body Burdens Causing Adverse Effects

The pollutant level in whole bodies, as well as in blood, fat, hair, skin, or other easily sampled tissues associated with toxicity (such as a metabolic change) are not well studied. Such information is required for the development of mathematical models which predict when a pollutant will have a significant effect, and for predicting the possible environmental impacts of incrementally increasing the environmental level of a pollutant.

7.3.7 Intermedia Exchange

The results of intermedia exchange of pollutants (including sediment sorption/desorption) need to be determined. An array of land models for deriving ambient level goals and MATEs needs to be developed that takes into consideration contact with air and water (6). Air/water, air/land, water/sediment, land/water, and ultimately, air/land/water/sediment distribution coefficients need to be determined. eH/pH diagrams may help in this effort and similiarly need to be constructed. Information on the form in which the element is likely to be found (including eH/pH diagrams) should also be determined or made available.

7.3.8 Excretion Kinetics

The kinetics of excretion need to be better defined. This is an absolute requirement for mathematical modeling which predicts the body burden of a pollutant. For most of the essential trace metals, the transport and excretion patterns have been estimated, but only a start has been made on the excretion mechanisms of the toxic metals. In rats, cadmium can be excreted via the bile. Is this common for other metals? Do other routes of excretion play a significant part? Is the excretion of lead in bovine milk important (7)?

Some data on mercury excretion found by DeFreitas and coworkers (9) indicated that mercury excretion for several species of fish conforms to the following equation:

$$R = kPW^a$$

where (k) is the clearance coefficient, (P) is the body burden of pollutant, and (a) is the exponent of body weight for clearance having a value of -0.58.

Can an equation of this form be generalized to other pollutants and/or other species?

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